THUNDERSTORM FORECASTING

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Thesis by

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In this paper no attempt has been made to present a statistical study of thunderstorms but rather, by a study of individual cases, to arrive at a basis on which the forecasting of such phenomena may be predicated from the synoptic situation combined with the upper air soundings, if available. Since thunderstorms may be the result of one or more factors it was decided to arrange a classification, depending upon the particular factors, as follows:

1. Air mass thunderstorm.

    a. Convective.

    b. Orographical.

2. Frontal thunderstorm.

    a. Cold front.

    b. Warm front.

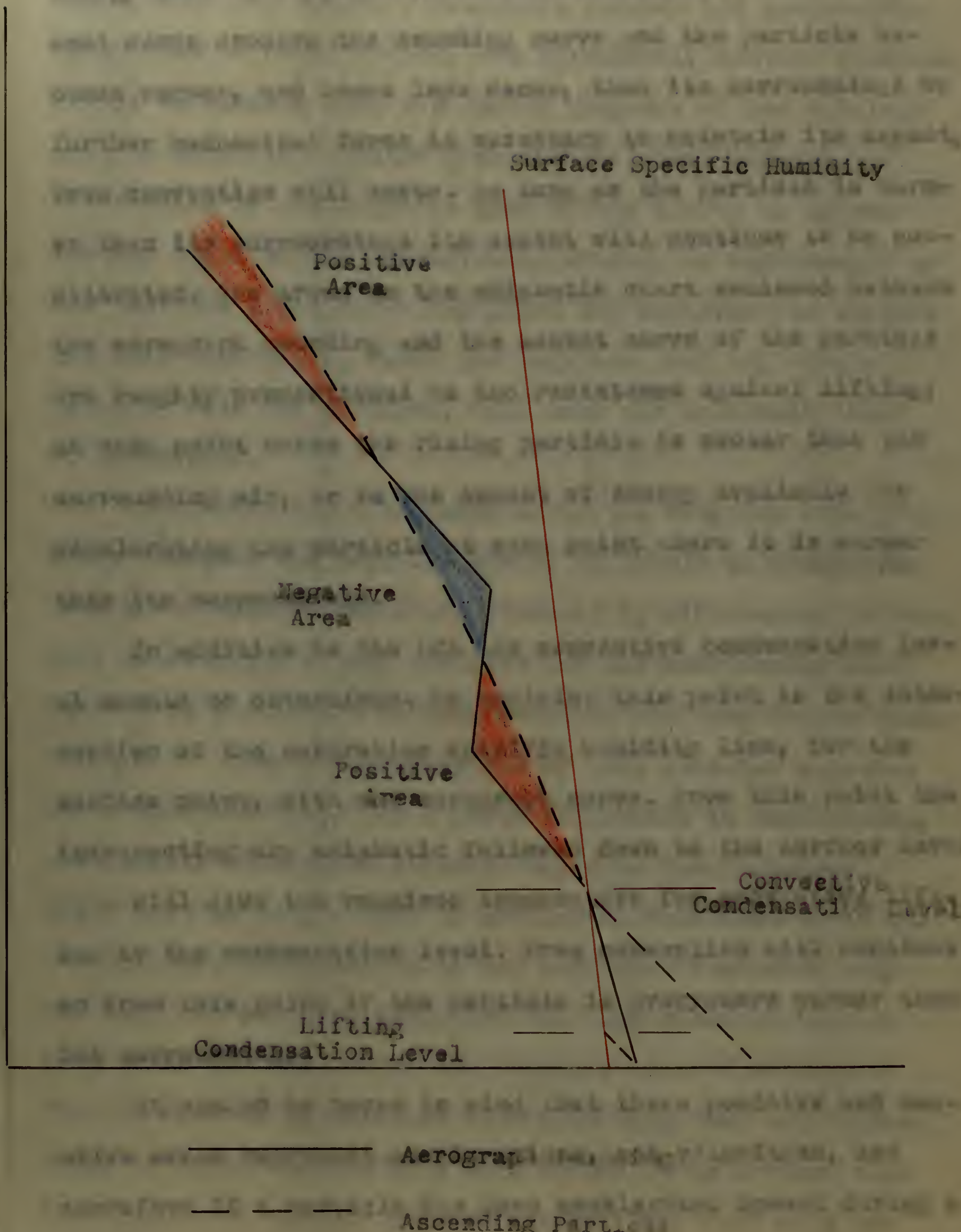
3. Pre-frontal thunderstorm due to a convergent field of motion.

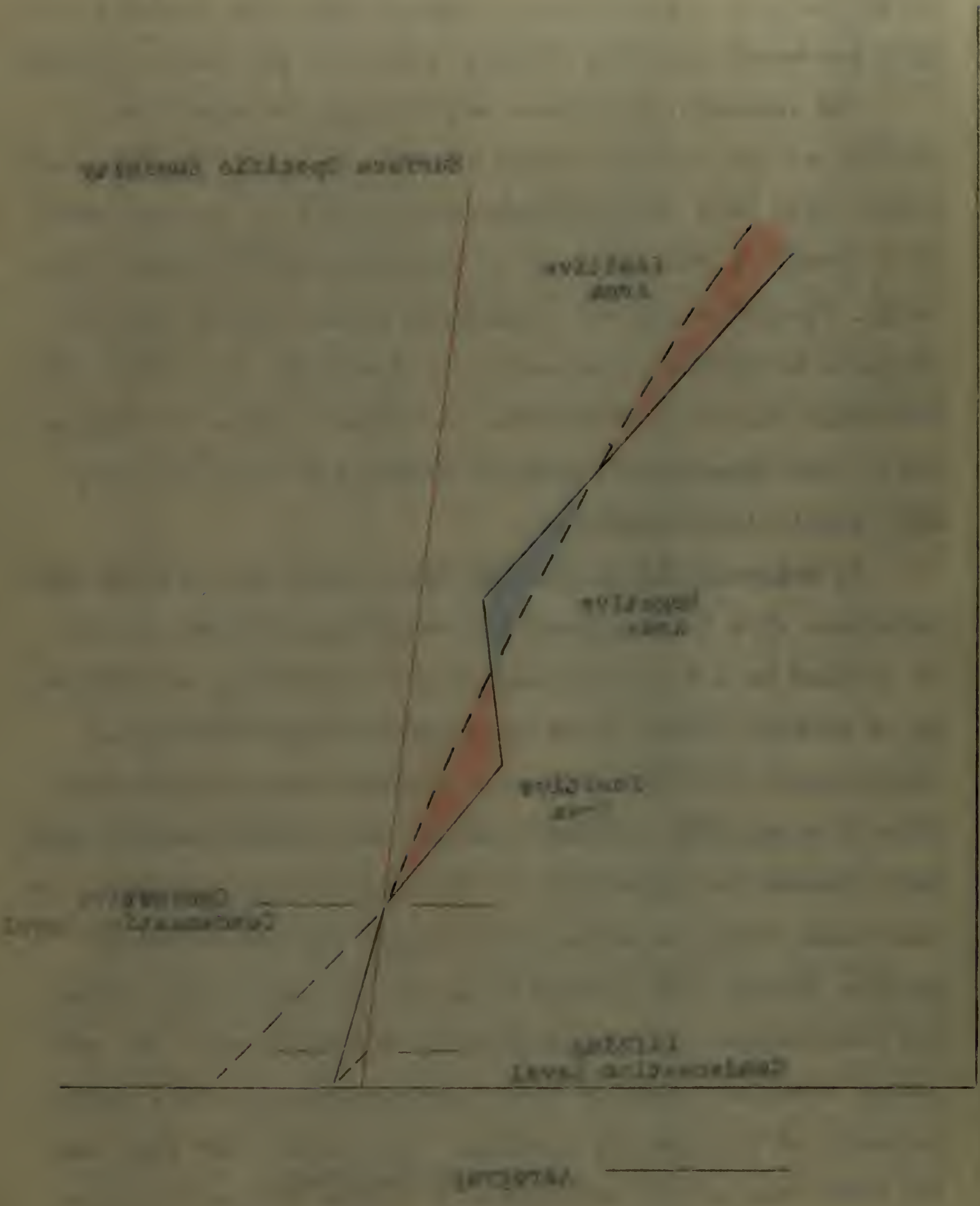
Before going into a detailed discussion of the types of thunderstorm it was considered advisable to summarize briefly the processes of their generation. First of all every thunderstorm, whether air mass or frontal, is produced by isolated penetrative convection, the result of an unstable

condition in the air mass, wherein the potential energy due to the initial distribution of temperature and moisture has been converted into the kinetic energy of the rising column.

The unstable conditions required may be developed by heating of the surface layers of the air, or by lifting the entire mass over an orographic obstruction or frontal surface; providing the air mass is initially conditionally unstable. Factors which may contribute to the development of unstable conditions, but which, in the light of present day knowledge cannot be considered as primary causes of instability, are convergent fields of motion and radiation from high level cloud systems.

To determine if conditions exist which may lead to the formation of a thunderstorm the aerograph sounding should be plotted on a meteorological chart, preferably an adiabatic or similar chart, since the graphic representation of thunderstorm conditions is most readily recognizable there. After the sounding has been plotted the lifting condensation level should be determined. To explain; an air particle, not saturated, which is lifted will follow the dry adiabatic passing through the surface point to its saturation point, the intersection of that particular adiabatic with the saturated specific humidity line corresponding to the specific humidity of the surface particle. This point, the LCL, having been reached the particle will follow the moist adiabatic as it ascends further. However, as long as the rising


Surface Specific Humidity
Positive Area
Negative Area
Positive Area
Lifting Condensation Level


Surface Specific Entropy
Positive Area
Negative Area
Positive Area
Convective Condensation Level
Lifting Condensation Level
Actual
Ascending Parcel

particle is cooler than the surrounding air at the same level energy must be supplied to further its ascent. When the ascent curve crosses the sounding curve and the particle becomes warmer, and hence less dense, than its surroundings no further mechanical force is necessary to maintain its ascent, free convection will ensue. As long as the particle is warmer than its surroundings its ascent will continue to be accellerated. The areas on the adiabatic chart enclosed between the aerograph sounding and the ascent curve of the particle are roughly proportional to the resistance against lifting, at each point where the rising particle is cooler than the surrounding air, or to the amount of energy available for accelerating the particle at each point where it is warmer than its surroundings.

In addition to the LCL the convective condensation level should be determined. To explain; this point is the intersection of the saturation specific humidity line, for the surface point, with the aerograph curve. From this point the intersecting dry adiabatic followed down to the surface level will give the required temperature for convective lifting to the condensation level. Free convection will continue on from this point if the particle is everywhere warmer than its surroundings.

It should be borne in mind that these positive and negative areas represent accelerations, not velocities, and therefore if a particle has been accelerated upward during a

portion of its ascent, as shown by a positive area on the chart, and then enters a resistant stratum its upward velocity will be decellerated, not necessarily halted. However, it may be assumed that the upward progress of the particle will be completely halted when the resistant stratum, as represented by the negative area on the chart, is approximately equal to the accelerating areas, as represented by the positive area, which has given the particle its initial impetus; this point, where the negative area has reached equality with the positive, will mark the uppermost limit of convection.

In arriving at a decision as to the relative effect of these positive and negative areas, it should be remembered that their accelerations are produced by differences in density between the rising particle and the surrounding air. Density is a function of both pressure and temperature since $\rho = \frac{P}{RT}$. From a consideration of this familiar equation it is apparent that, for a given difference in temperature, the density difference depends only upon the pressures, which must be equal. Thus an area of a given size at an altitude where the pressure is 500 millibars indicates only one half the acceleration which the same sized area would have at an altitude where the pressure is 1000 millibars. Thus an area of appreciable size appearing near the surface level is an indication of a more violent thunderstorm than if it appeared at 3000 or 4000 meters. This fact will become more apparent after an examination of the thunder-

portion of its extent, or would be a negative area on the chart and thus render a statistical picture the reverse rel-ative will be meaningless, and essentially without meaning. It may be assumed that the upward progress of the particle will be completely halted when the resultant attraction, as represented by the negative area on the chart, is approxi-mately equal to the accelerating energy, as represented by the positive area, which then gives the particle its initial velocity; this point, where the negative area has reached equality with the positive, will mark the approximate limit of convection.

In arriving at a definition of the relative values of these positive and negative areas, it should be remembered that their determinations are governed by the difference in den-sity between the rising particle and the surrounding air. Density is a function of both pressure and temperature since $\rho = \frac{p}{RT}$. From a consideration of this simple equation it is apparent that, for a given difference in temperature, the density difference becomes less with the altitude, which must be a fact. This is done by a large scale of [illegible] [illegible] where the pressure at the different levels is only one half the sea-level pressure that [illegible] there at an altitude where the pressure is [illegible]. Thus an area of [illegible] this [illegible] near the surface [illegible] of [illegible] of a more [illegible] [illegible] than if [illegible] at [illegible] or [illegible]. This fact will be-come more apparent after an examination of the [illegible].

storm examples which follow.

Once the air particles have reached the condensation level, either due to lifting or surface heating, clouds will be formed. Although not definitely established, it is believed that the water droplets in the cloud will not form raindrops until convection has reached the ice crystal level, the point where the rising particle crosses the zero isotherm. There, ice crystals mixing with, or falling through, the water droplets serve as nuclei for the formation of raindrops. It may be assumed that precipitation will not begin until the top of the cloud has reached the ice crystal level.

Another assumption is that the potential gradient necessary for the development of thunderstorms is established by the splitting of raindrops as a result of violent ascending currents within the cloud. The minimum value of the upward velocity necessary to produce this effect is commonly assumed to be 8 meters per second.

Included here is a series of hypothetical situations where various degrees of instability are represented. Each will produce different phenomena, ranging from the formation of a cumulus cloud without rain to the formation of a violent thunderstorm accompanied by hail. By means of these diagrams the type of phenomena to be expected, from the representative areas on an adiabatic chart, can be estimated in clear cut cases.

Type # 1. This situation would result in the formation of cumulus clouds without precipitation since the positive a area is approximately equal to the negative and the ICL is above the point where convection ceases.

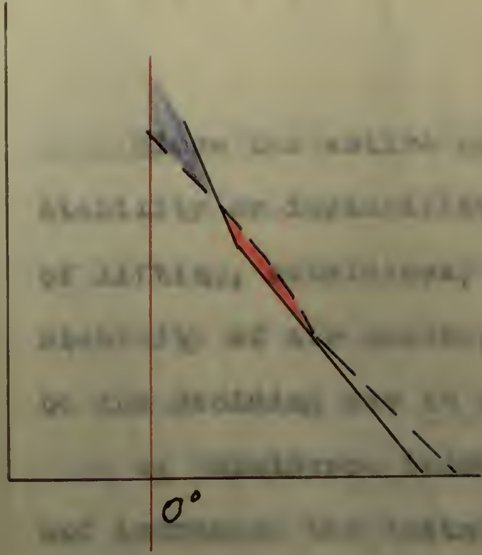
Type # 2. This situation would result in the formation of cumulus with showers since the convections extend above the ICL. However, a thunderstorm would not be expected since the vertical velocity attained by the rising air would not be sufficently strong, as shown by the fact that the area of available energy is small.

Type # 3. This situation would result in the formation of a thunderstorm since the convections extend above the ICL and the vertical velocity attained by the rising air would be sufficently strong to disrupt the raindrops and establish the potential gradient required for an electrical display. However, hail would not be expected since the area of positive area above the ICL is small.

Type # 4. This situation would result in the formation of a light thunderstorm, accompanied by hail, since the convections extend well above the ICL and the vertical velocity, while reaching appreciable value at the ICL, will continue to be accelerated for a considerable distance above that point. This is indicated by the large positive area. This situation is common in winter months in southward moving polar maritime masses.

Type # 5. This situation would result in the formation of a violent thunderstorm accompanied by hail, since the vertical velocities attained prior to reaching the ICL would be exceedingly large as indicated by the large positive area below that point. Above the ICL there is further increasing positive area which would increase the accelerations far above that point.

From the above hypothetical situations is would seem that the size of the positive area below the ICL determines whether a shower or a thunderstorm will develop from a given situation and is a measure of the intensity of the thunderstorm. Similarly the size of the positive area above the ICL is a measure of the probability of hail.



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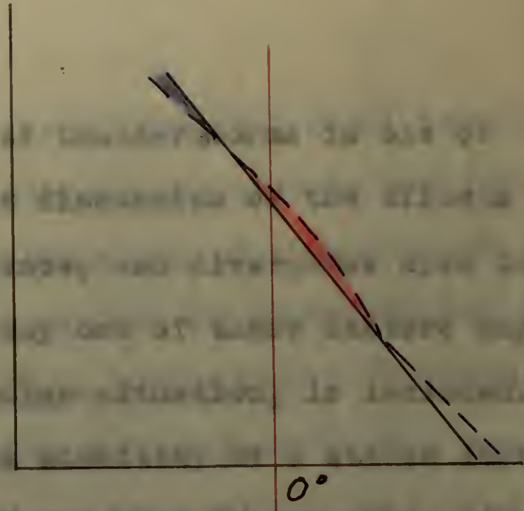

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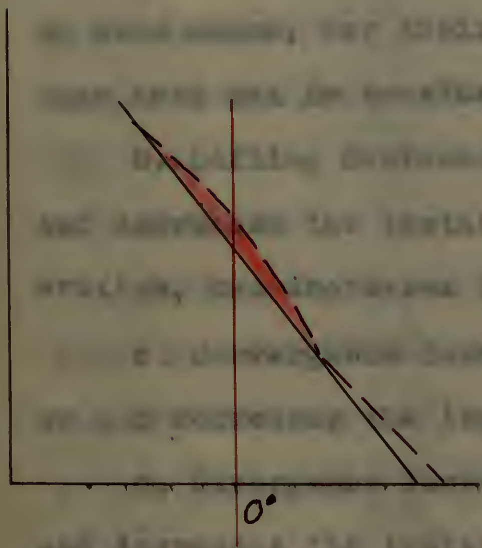

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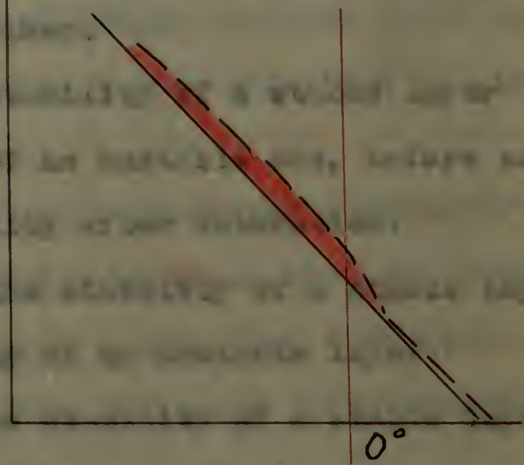

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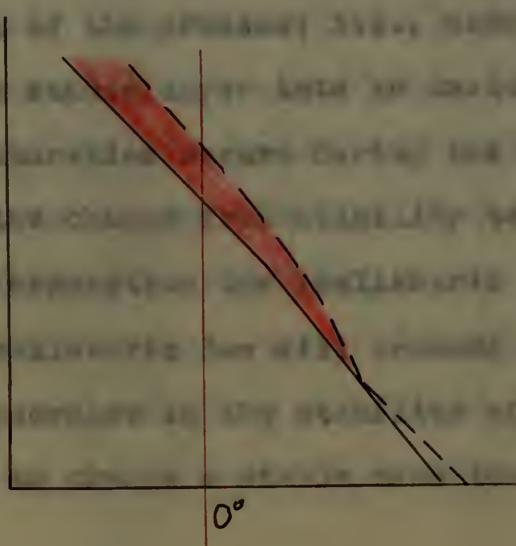

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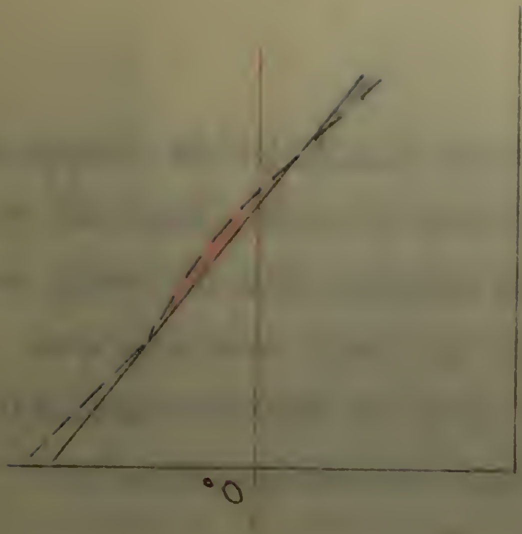
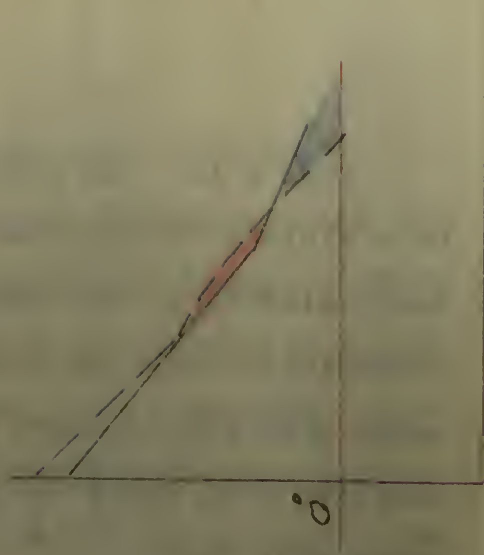
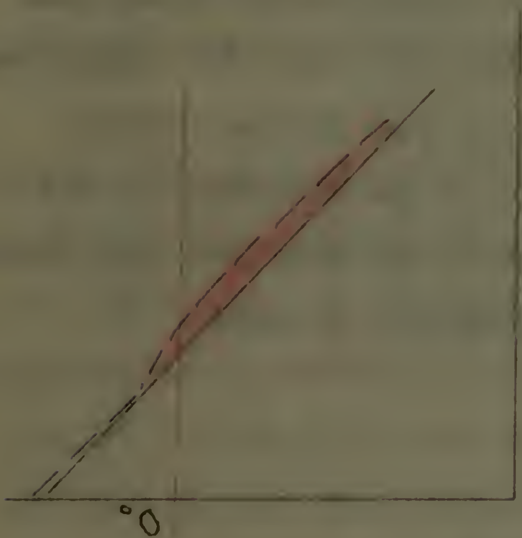
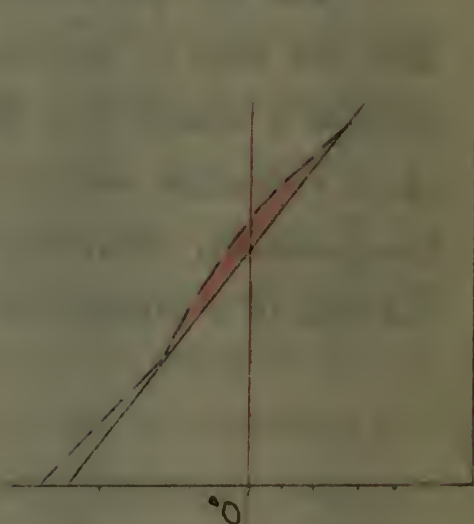
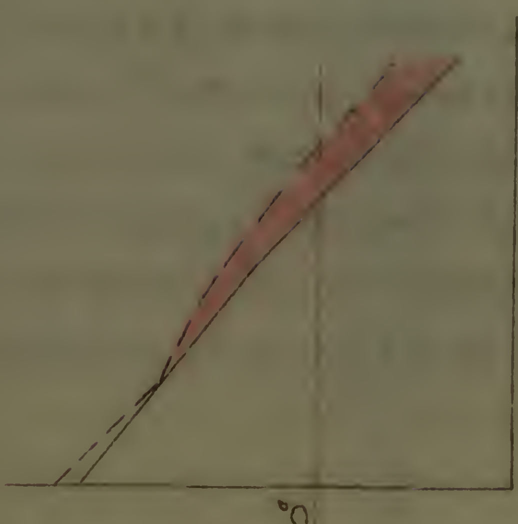










Since the entire question of thunderstorms is one of stability or instability a brief discussion of the effects of lifting, subsidence, convergence, and divergence upon the stability of air masses, since any one of these factors may be the deciding one in a particular situation, is included.

a. Subsidence increases the stability of a stable layer and increases the instability of one already unstable. Since thunderstorms require lifting of particles or strata of air, by some means, for their formation, the effects of subsidence need not be considered further.

b. Lifting decreases the stability of a stable layer and decreases the instability of an unstable one, before saturation, but increases instability after saturation.

c. Convergence decreases the stability of a stable layer and decreases the instability of an unstable layer.

d. Divergence increases the stability of a stable layer and increases the instability of an unstable layer.

In all the above cases neutral stability is the limit of the effect of the process; i.e., none of the processes can convert a stable layer into an unstable one or vice versa, unless saturation occurs during the process and in itself causes the change from stability to instability.

In this connection the isallobaric field is a potent factor, an isallobaric low will produce convergent flow with a resultant decrease in the stability of the air. This may be sufficent to change a stable mass to one conditionally

unstable with resultant thunderstorm activity. Thus, inspection of an aerograph sounding without reference to the synoptic chart might indicate no probability of thunderstorms. However, the change in structure of the air mass produced by a strong convergent field of motion, indicated by the presence of strong negative tendencies on the weather map, may be sufficent to produce conditional instability. As far as is known there is at present no means of making a quantitative determination of the effect of convergence upon stability; therefore estimation of its effect must be based upon experience. An example of this particular situation is given in section one.

Conversely an isallobaric high, producing a divergent flow, may stabilize a conditionally unstable mass and prevent the formation of thunderstorms although an inspection of the aerograph sounding may have indicated their probability.

Here also it is well to note that divergent flow, although commonly associated with subsidence, is always present in air overrunning a warm front, except near a well developed low pressure center, and also may be present in air being lifted orographically. In case of conditionally unstable air which is saturated by the lifting process, frontal or orographical, this divergent flow adds to the instability produced. Thus air flowing from a warm sector, in which there are negative tendencies, overrunning a warm

front is subjected successively to convergence, lifting and finally divergence, each process tending to produce instability.

Another factor which must be considered in estimating the changes in the structure of an air mass after the aerograph sounding has been made is the development of large scale turbulence due to a large vertical velocity gradient. Turbulence tends to produce a state of neutral equilibrum, either for the dry or saturated state, depending upon the amount of moisture present. This reduces the relative humidity of the surface layer and thus raises the CCL and the maximum temperature required for free convection. In addition, air having a maximum of moisture in the upper layers, an effect of turbulence, being subjected to lift will be made more stable since the upper layers would reach saturation before the lower and thereafter cool at the moist adiabatic rate while the lower levels would still be cooling at the steeper dry adiabatic rate. On the other hand, even though a sounding may show the presence of a large inversion or stable layer which will block convective activity, turbulence may be sufficent to alter this structure and permit thunderstorm development which would not be anticipated if this factor were not considered.

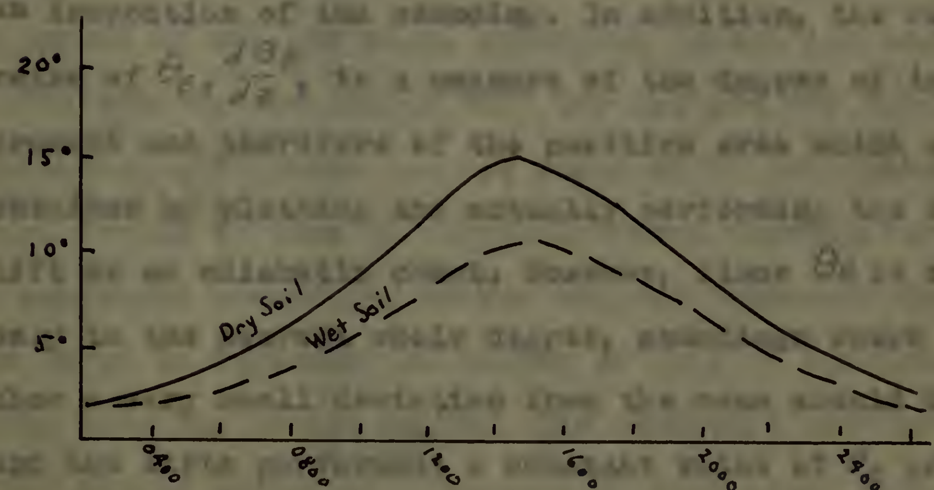
The choice of specific humidity of the point to be raised by convection from insolational heating is, of course, of considerable importance. Normally, on days when convective activity is going to occur, the early morning hours will be clear and a surface inversion developed by nocturnal radiation. In this case it is customary to take an average of the specific humidities of all points below the top of the inversion and use this value as the actual specific humidity of the point to be raised. This is particularily true if any wind is expected during the day which will mix the lower layers.

The exposure of the station must also be taken into consideration; thus if the flow of air is from a water surface, such as a coastal or lake station, no decrease in the surface specific humidity need be anticipated.

In forecasting the convective type of air mass thunderstorm a knowledge of the probable maximum temperature for the day and the rate of change of temperature during the day is essential.

The rate of change of temperature of the surface depends upon the amount of insolation received and the soil constants. The first is practically constant throughout the year for the same sky conditions but the latter vary widely from place to place, depending upon the amount of soil cover, the character of the soil and the amount of moisture present in the soil. Since these are too variable and difficult to ascertain, the

use of equations to determine rates of change of temperature does not yield results worthy of the amount of labor involved. Instead, for this purpose diurnal temperature curves for each month of the year, under the different sky and surface conditions, should prove to be of considerable assistance. These curves can be made up for clear, cloudy, partly cloudy days, and dry and wet soil. From thermograph records of past years, the amplitude of the curve and the variation from the mean for each hour or two hours obtained. These values can then be plotted on an arbitrary scale of temperature versus time and the general shape of the curve obtained. For example:



Needless to say, the curves for any two days under similar conditions will very probably have different absolute values but the general shape of the curves should be the same. The forecaster, knowing the amplitude of his curve, can apply this to his minimum temperature and determine whether the required temperature for convections can be reached.

In situations where lifting of an appreciable layer will be a factor in thunderstorm development the equivalent potential temperature, θ_E, of each salient point, together with the lift required to saturate each, is extremely valuable to the forecaster in his examination of the soundings available. Since values of θ_E, decreasing with increasing altitude, indicate potential instability, and the indicated lifts give the lift required to saturate a given stratum, the forecaster, after sufficent practice, can determine how much lift is required to release the conditional instability of the air mass in question, the thickness of the unstable layer, and the point where free convection will start, from an inspection of the sounding. In addition, the rate of decrease of θ_E, $\frac{d\theta_E}{dz}$, is a measure of the degree of instability present and therefore of the positive area which would be obtained by plotting and actually performing the required lift on an adiabatic chart. However, since θ_E is reported only to the nearest whole degree, soundings where the values show a very small deviation from the mean should be plotted and the lifts performed; a constant value of θ_E would indicate neutral equilibrium for the saturated state and hence that a thunderstorm would be impossible since no vertical accelerations would be developed. An example of this is given in warm front situation #1; the sounding shows a constant value of θ_E, 329°, from the surface up to 2.80 meters. However, actually working it out on an adiabatic chart shows that a slight degree of conditional instability does exist.

Throughout this paper all soundings have been plotted and the lifts actually performed on an adiabatic chart. Since it is difficult to conceive of lifting taking place in the atmosphere without divergence at some level, the lifts have been performed with respect to the altitude scale and not the pressure scale. This procedure introduces approximately 8% divergence in a lift of one kilometer, which is considered to be conservative. However this is a very tedious process and should not, except in border line cases, be necessary after the forecaster has become familiar with the use of θ_E and lift.

AIR MASS SYMBOLS

In the following examples the customary method of classification of air masses is used, such as Tp, Pc, etc. In addition the symbol of any air mass, returning toward its source region is preceeded by the letter "R"; for example RPc denotes polar continental air, which has not remained in low latitudes a sufficient length of time to assume tropical characteristics, returning northward toward its source region. Subscript numerals are also added to indicate the number of days an air mass has been moving from its source region. The subscript entered to the left of the symbol indicates a trajectory over water surfaces, entered to the right indicates trajectory over land areas, e.g., $_1$Pp signifies polar pacific air one day from its source, with a water trajectory. The use of "o" as a subscript designates travel for a considerable period of time, sufficient that the air has lost its original characteristics but has not assumed the char-

acteristics of air typical of the region over which it is moving, e.g., oRPc signifies polar continental air returning northward after a trajectory over water of several days duration but not sufficently long for complete assumption of Tg or Ta character.

SECTION ONE

AIR MASS THUNDERSTORMS

Under this category are included those thunderstorms occurring in the absence of frontal activity; those caused by surface heating and orographical lifting. This type is of course more frequent in the summer months. They may occur in almost every type of air mass, but are observed most frequently in Tg and Ta masses due to the typical structure of conditional instability and large moisture content inherent in them. However, they are observed on the Pacific Coast in winter in fresh Pp air; illustrations of this type are included in this section.

In the foregoing section the general mechanics of thunderstorm formation have been discussed, and mention made of the factors which, within the forecast period, may alter the structure of the air from that shown by the original aerograph curve to a structure, either more or less favorable to thunderstorm production. In addition, a classification with respect to the type of phenomenon to be expected from a given structure, once convections were established, was given.

In this section several examples of air mass thunderstorms are presented, with a brief description of what appear to be the salient features of each. Unfortunately, in the reports, the relative intensity of the thunderstorm and the type and amount of precipitation are frequently not given. Where possible, this has been estimated by consideration of

of the precipitation reports on the weather maps. However, these can by no means be considered conclusive, since by its very nature thunderstorm precipitation is sporadic; and the reports received from two closely adjoining stations may be widely variant.

EXAMPLE # 1.

Pensacola, Florida. 28 April, 1936.

This is type # 3, air mass thunderstorm situation.

First, consideration of the synoptic chart shows the forecaster the air mass or masses with which he is dealing. In this case the synoptic chart shows that, during the forecast period, he will be dealing with but one air mass, characterized as R_3Pc_1, approaching Tg, but emphatically not a true Tg air mass as is clearly borne out by the aerograph sounding which shows the stratified moisture distribution typical of old Pc in this region. Incidentally this stratification gives a very much more violent reaction when lifted, convectively or frontally, than pure Tg with its more symmetrical moisture gradient.

The explanation of the choice of the specific humidity to be used for the rising particle has been given above; in this case, due to the location of the station on the Gulf of Mexico where the surface levels are assured an ever fresh supply of moisture, with on-shore winds, the actual specific humidity, 1[illegible] grams per kilogram, of the surface point is chosen.

Inspection of the adiabatic chart shows the LCL at 1008 millibars, 140 meters. If the moist adiabatic is followed up from this point it will show a small negative, resistant, area to 920 millibars. Unless there is some synoptic factor, or an orographic obstruction, to change the structure of the air or to further mechanically lift it no convections from lifting would be expected to take place. In this case no such conditions were present so attention is given to the CCL.

Inspection shows the CCL at 952 millibars, 600 meters; the dry adiabatic followed from here to the surface point shows that a maximum temperature of 25.6° C. is required to establish free convections from insolational heating. An examination of the diurnal temperature curves for this station shows that such a temperature is not excessive for the date.

Since free convection is a probability return to the CCL and follow the moist adiabatic up from that point. It is seen that everywhere the aerograph curve is colder than the path followed by a surface particle moving up the moist adiabatic from the CCL; in short, that there is positive area at all points which would accelerate a particle for a distance of 3900 meters from the CCL to the ICL, and for some distance, which, due to the termination of the aerograph sounding, cannot be determined, beyond that point.

A thunderstorm should be predicted for the station. Since the ICL is very high, 582 millibars, 4500 meters, and the structure above that point cannot be completely pictured, it would be safer to predict only rain with it, hail probably

would not reach the surface. The time at which convections would reach the condensation level could be predicted quite accurately by use of the diurnal temperature curves and the adiabatic chart, but predicting the hour at which the thunderstorm would break, or how long it would last, is a fine point which will not be attempted here.

A thunderstorm of considerable intensity accompanied by 1".12 of rain, and gusts of 35 knots, occurred at the station at 1830.

TIME SOUNDING 0 5-3-3 EST

COMPUTED BY FAB

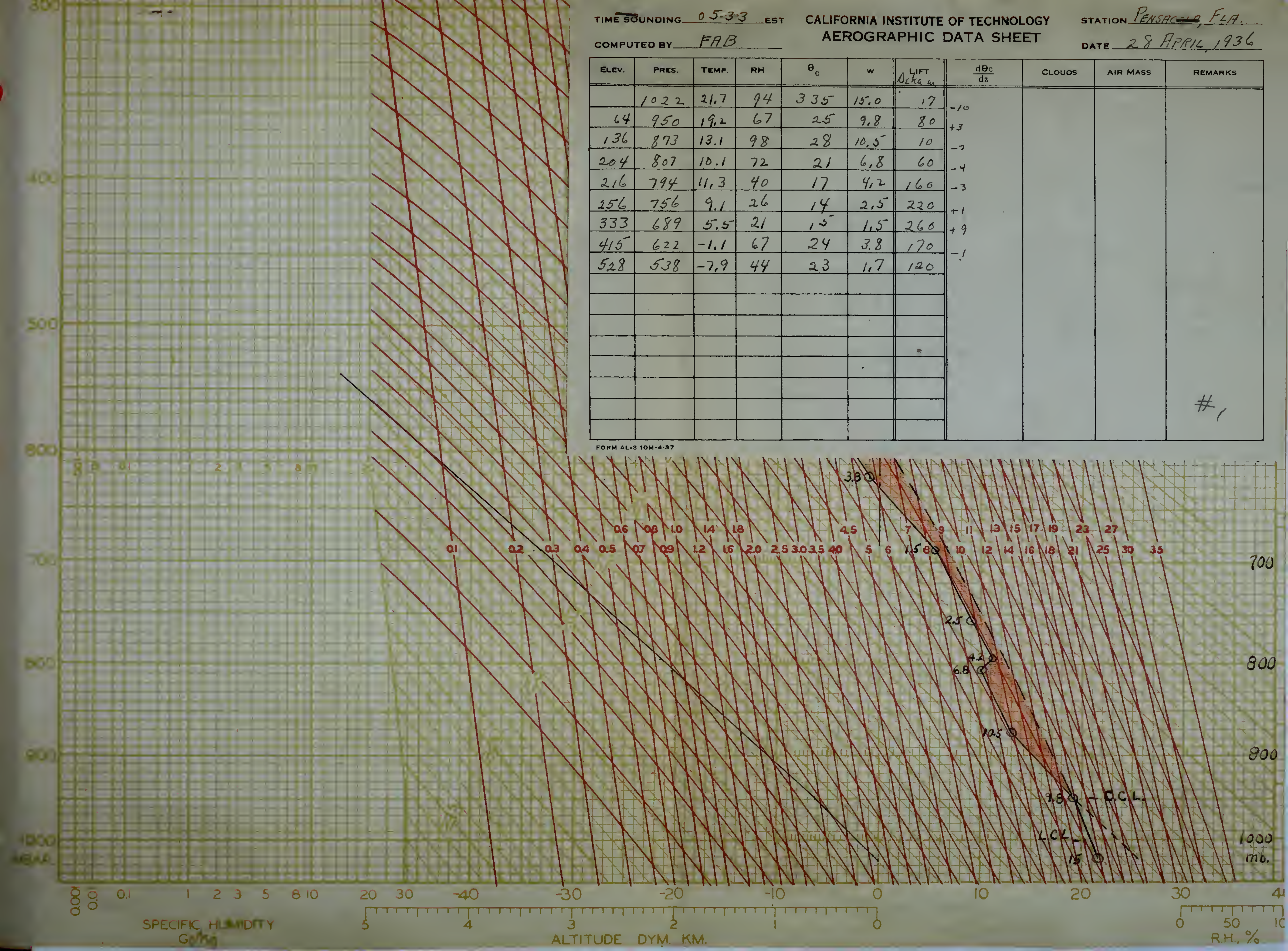
CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

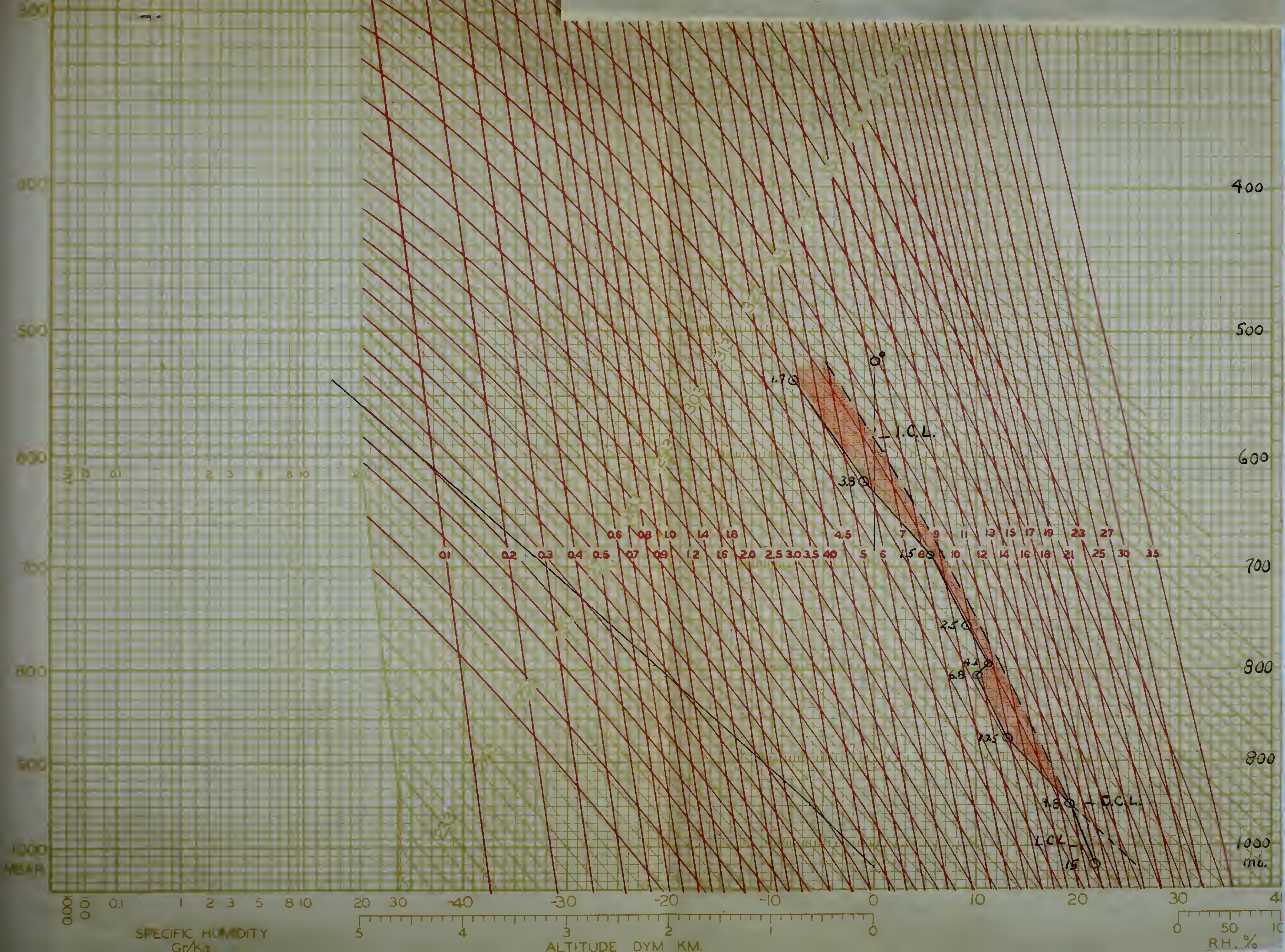
STATION Pensacola, Fla.

DATE 28 April, 1936

Elev.	Pres.	Temp.	RH	θ_c	w	Lift Dcka m	$\frac{d\theta c}{dz}$	Clouds	Air Mass	Remarks
	1022	21.7	94	335	15.0	17	-10			
64	950	19.2	67	25	9.8	80	+3			
136	873	13.1	98	28	10.5	10	-7			
204	807	10.1	72	21	6.8	60	-4			
216	794	11.3	40	17	4.2	160	-3			
256	756	9.1	26	14	2.5	220	+1			
333	689	5.5	21	15	1.5	260	+9			
415	622	-1.1	67	24	3.8	170	-1			
528	538	-7.9	44	23	1.7	120				
										#1

FORM AL-3 10M-4-37





400
500
600
700
800
900
1000
mb.
MBAR
I.C.L.
C.C.L.
LCL
0°
1.7
3.8
2.5
4.2
6.8
10.5
9.8
15
SPECIFIC HUMIDITY
Gr/Kg
ALTITUDE DYM KM.
R.H. %

EXAMPLE # 2.

Pensacola, Florida. 21 May, 1936.

This is type # 3, air mass thunderstorm situation.

As in case one, first consideration is given to the synoptic chart to determine the air mass with which the forecaster is dealing. In this case the air mass is T_g.

The actual specific humidity of the surface point, 15.5 grams per kilogram, is chosen to determine the LCL and the CCL.

The LCL is found to be at 1007 millibars, 130 meters. Here, again, mechanical lifting to an extent which can not be realized, or a change in the structure of the air mass, which the synoptic chart shows not to be probable, would be required for convective action from lifting.

The CCL is found to be at 920 millibars, 930 meters. The dry abiabatic followed from here to the surface point shows that a maximum temperature of 28° C. is required for free convection to take place. Inspection of the station diurnal temperature curves shows that such a temperature is not excessive for the date.

Returning to the adiabatic chart and following the moist adiabatic up from the point where it intersects the CCL it is seen that everywhere above that point lies a positive area. A particle leaving the CCL would be accelerated for 4170 meters to the ICL and for a distance beyond that point which can not be estimated.

A thunderstorm should be predicted for the station. Since the ICL is very high, 560 millibars, 5000 meters, and the structure above that point cannot be completely pictured it would be safer to predict only rain to accompany it, hail probably would not reach the surface.

A thunderstorm of slight intensity accompanied by a trace of rain, no recorded gusts, occurred at the station at 1700.

TIME SOUNDING 0607 EST

CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

STATION Pensacola, Fla.

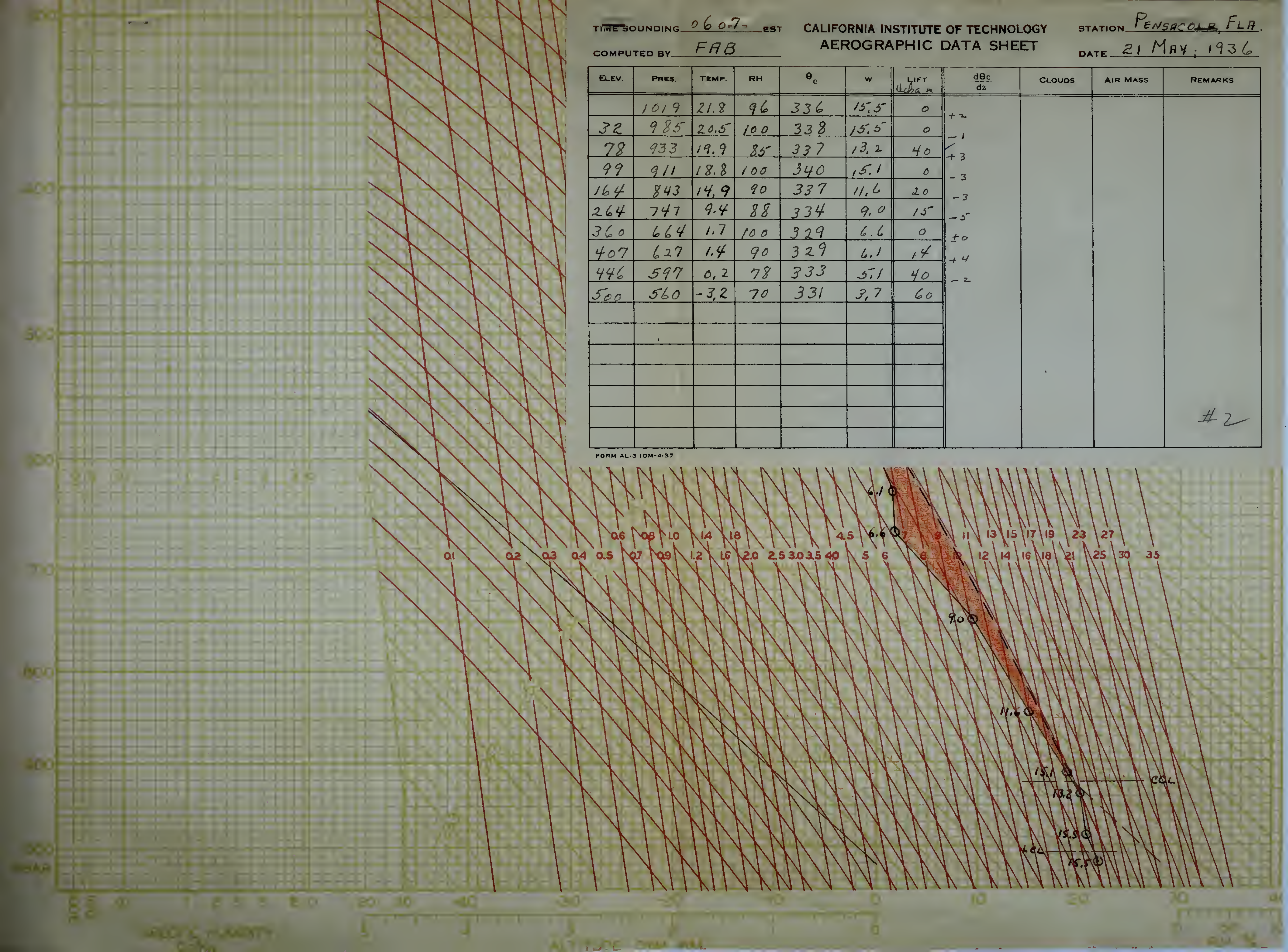
COMPUTED BY FAB

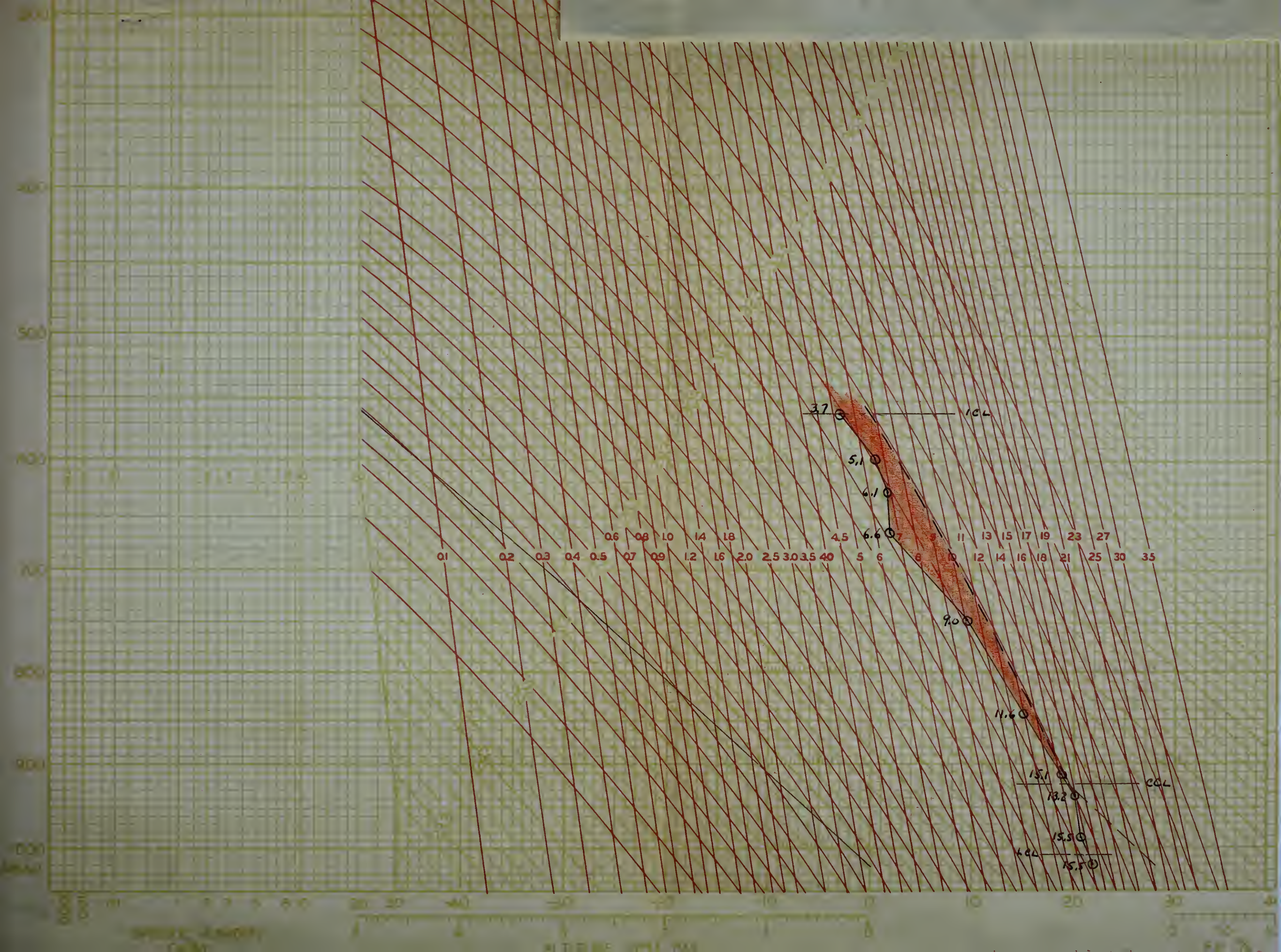
DATE 21 May, 1936

Elev.	Pres.	Temp.	RH	θ_c	w	Lift	$\frac{d\theta_c}{dz}$	Clouds	Air Mass	Remarks
	1019	21.8	96	336	15.5	0	+2			
32	985	20.5	100	338	15.5	0	−1			
78	933	19.9	85	337	13.2	40	+3			
99	911	18.8	100	340	15.1	0	−3			
164	843	14.9	90	337	11.6	20	−3			
264	747	9.4	88	334	9.0	15	−5			
360	664	1.7	100	329	6.6	0	±0			
407	627	1.4	90	329	6.1	14	+4			
446	597	0.2	78	333	5.1	40	−2			
500	560	−3.2	70	331	3.7	60				

#2

FORM AL-3 10M-4-37





3.7
ICL
5.1
6.1
6.6
9.0
11.6
15.1
CCL
13.2
15.5
LCL
15.5
0.6 0.8 1.0 1.4 1.8 4.5 7 9 11 13 15 17 19 23 27
0.1 0.2 0.3 0.4 0.5 0.7 0.9 1.2 1.6 2.0 2.5 3.0 3.5 4.0 5 6 8 10 12 14 16 18 21 25 30 35

EXAMPLE # 3.

Pensacola, Florida. 21 August, 1936.

This is type # 3, air mass thunderstorm situation.

The synoptic chart indicates that the forecaster will deal with but one air mass during the forecast period, Tg.

In this case, due to the small temperature inversion, which should be wiped out shortly after the sun rises, the mean of the actual specific humidities of the first two points, 18.1 grams per kilogram, is chosen as the actual specific humidity of the particle to be lifted.

The LCL is found to be at 962 millibars, 440 meters. Since mechanical lifting in this amount cannot be provided here, attention is turned to the CCL.

The CCL is found to be at 908 millibars, 970 meters. The maximum temperature of 31°.2 C. found to be required for free convection is checked on the station diurnal temperature curves and found not excessive for the date.

If the moist adiabatic is followed up from the point where it intersects the CCL it will be found that positive area is present to the top of the curve. A particle leaving the CCL would be accelerated for 4770 meters to the ICL and for a distance beyond that point which cannot be estimated.

A thunderstorm should be predicted for the station. Since the ICL is very high, 512 millibars, 5740 meters, and the structure above that point cannot be completely pictured, it would be safer to predict only rain to accompany the thun-

derstorm, hail probably would not reach the surface.

A thunderstorm of moderate intensity, accompanied by $0''.21$ of rain, no recorded gusts, occurred at the station at 1800.

TIME SOUNDING 0536 EST

COMPUTED BY

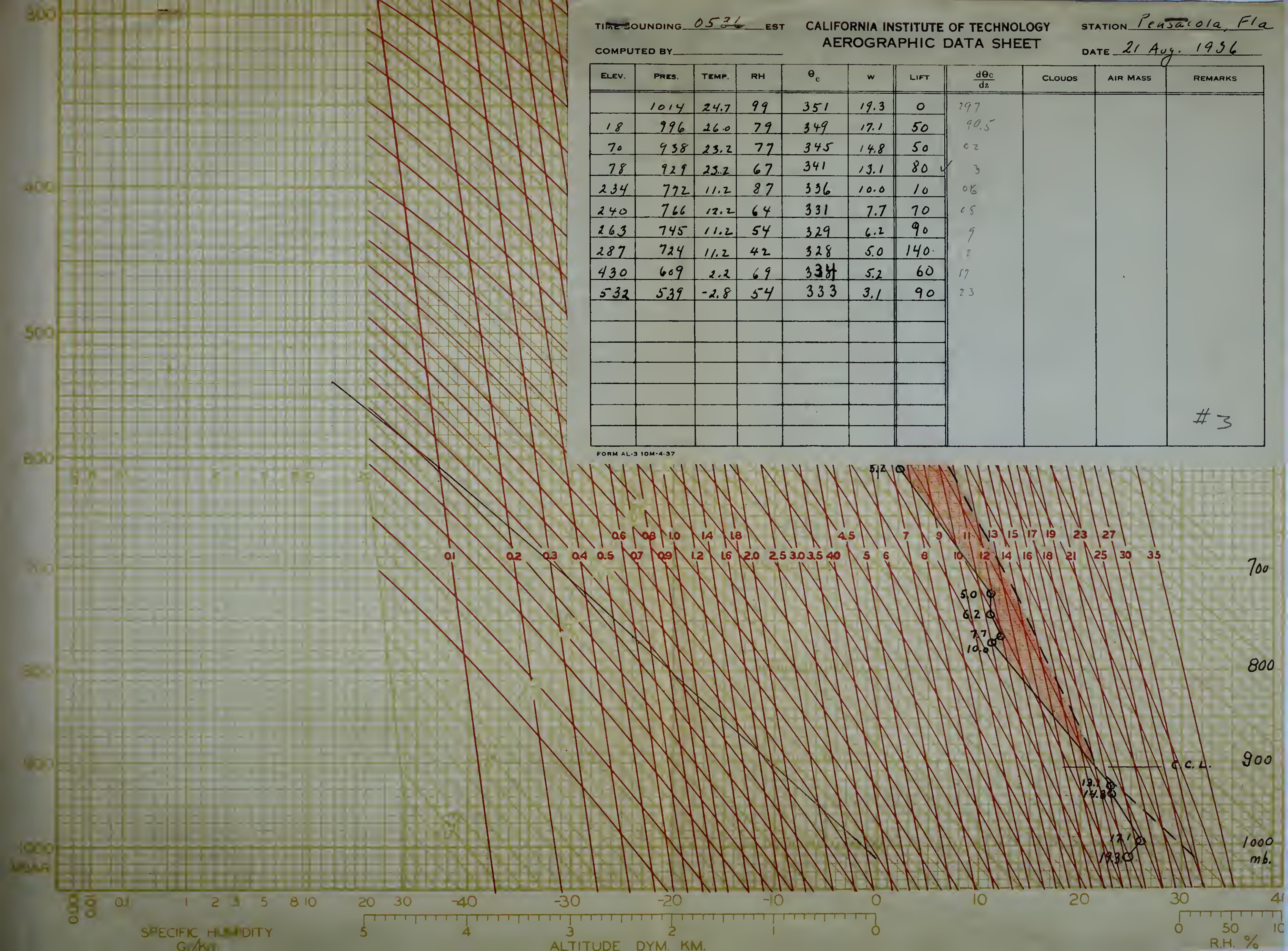
CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

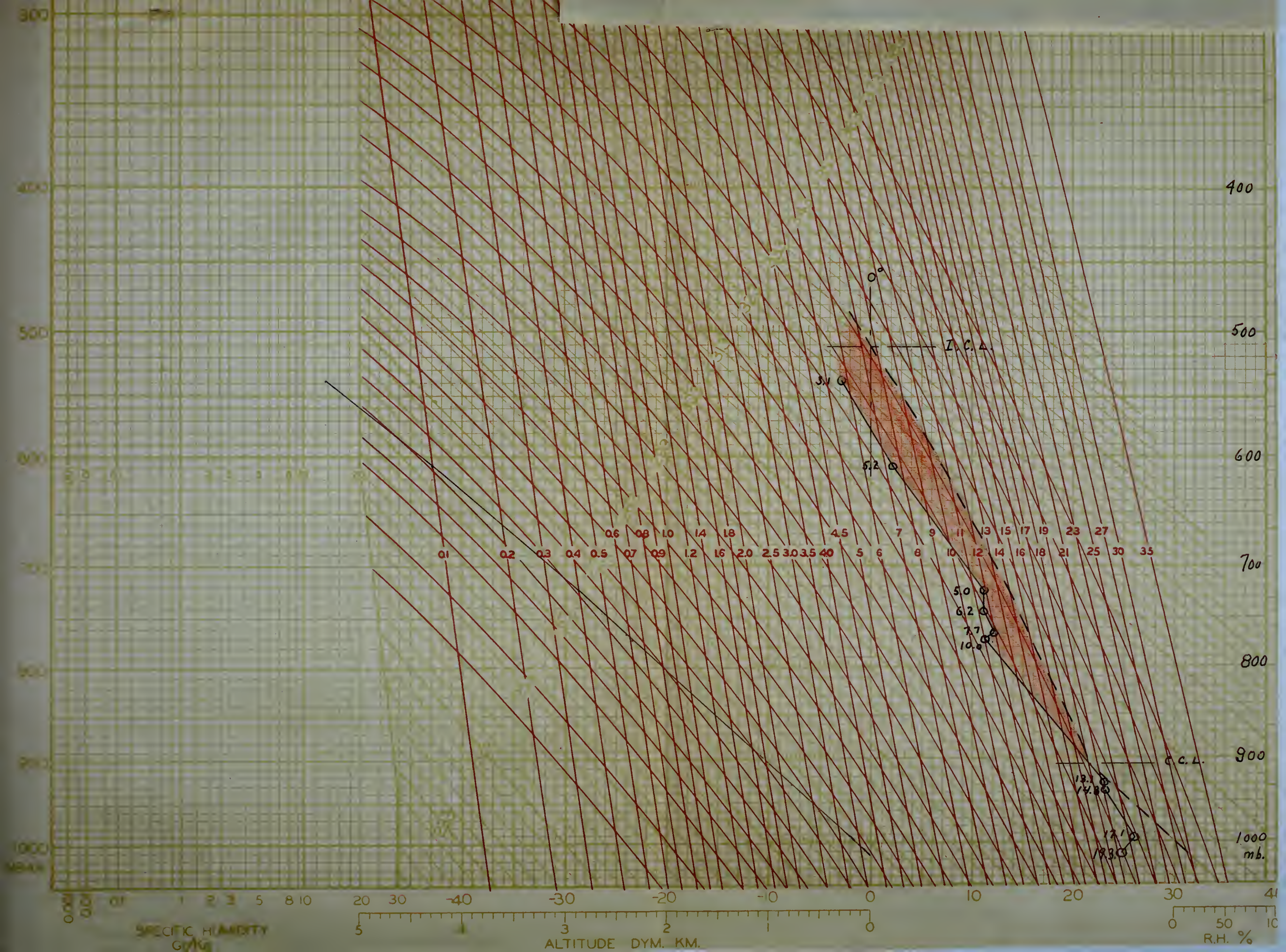
STATION Pensacola, Fla

DATE 21 Aug. 1936

ELEV.	PRES.	TEMP.	RH	θ_e	W	LIFT	$\frac{d\theta_e}{dz}$	CLOUDS	AIR MASS	REMARKS
	1014	24.7	99	351	19.3	0	297			
18	996	26.0	79	349	17.1	50	90.5			
70	938	23.2	77	345	14.8	50	02			
78	929	23.2	67	341	13.1	80 ✓	3			
234	772	11.2	87	336	10.0	10	06			
240	766	12.2	64	331	7.7	70	08			
263	745	11.2	54	329	6.2	90	9			
287	724	11.2	42	328	5.0	140	2			
430	609	2.2	69	334	5.2	60	17			
532	539	-2.8	54	333	3.1	90	23			
										#3

FORM AL-3 10M-4-37





400
500
600
700
800
900
1000 mb.
0°
I. C. L.
C. C. L.
3.1
6.2
5.0
6.2
7.7
10.0
13.1
14.8
17.1
19.3
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.2 1.4 1.6 1.8 2.0 2.5 3.0 3.5 4.0 4.5 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 23 25 27 30 35
-40 -30 -20 -10 0 10 20 30 40
SPECIFIC HUMIDITY G/KG
ALTITUDE DYM. KM.
R.H. %

EXAMPLE # 4.

Anacostia, Virginia.   10 July, 1936.

This is type # 3, air mass thunderstorm situation.

This and the following case, #5, are introduced to indicate that thunderstorm forecasting is not always certain. From a consideration of the synoptic chart and the adiabatic chart it is not believed that many forecasters would have predicted thunderstorms for this day. Since the possibility of lifting setting off free convection is indicated as impossible, no frontal activity being involved and orographic obstacles lacking sufficent height, the only possibility of thunderstorms would be convection due to insolational heating. A maximum temperature is required for free convection which would not have been anticipated for this day. However, thunderstorms did occur on this day.

The synoptic chart shows that the forecaster will deal with but one air mass during the forecast period, Tg_3.

In this case, due to the large temperature inversion, which would have to be wiped out before free convection could arise, the mean of the actual specific humidities of the points from the surface to the top of the inversion, 12 grams per kilogram, is chosen as the actual specific humidity of the surface particle to be lifted by convection.

The CCL is found to be at 678 millibars, 3420 meters, and the temperature required for free convection to be 43° C. This would seem excessive, but since that temperature was

reached on this day it will be followed through on the adiabatic chart.

When the CCL is reached by convections due to insolational heating it is found that, following the moist adiabatic up from its intersection with the CCL, everywhere above that point will be positive area. The ICL is very high, 530 millibars, 5400 meters, and the whole structure of the positive area cannot be pictured, but a particle will be continuously accelerated from the CCL for 2260 meters to the ICL and for some distance beyond that point. A thunderstorm should have been predicted for the station.

A high level thunderstorm of slight intensity occurred over the station at 2100. No record of type or amount of precipitation.

______EST CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

STATION Anac
DATE 10 July

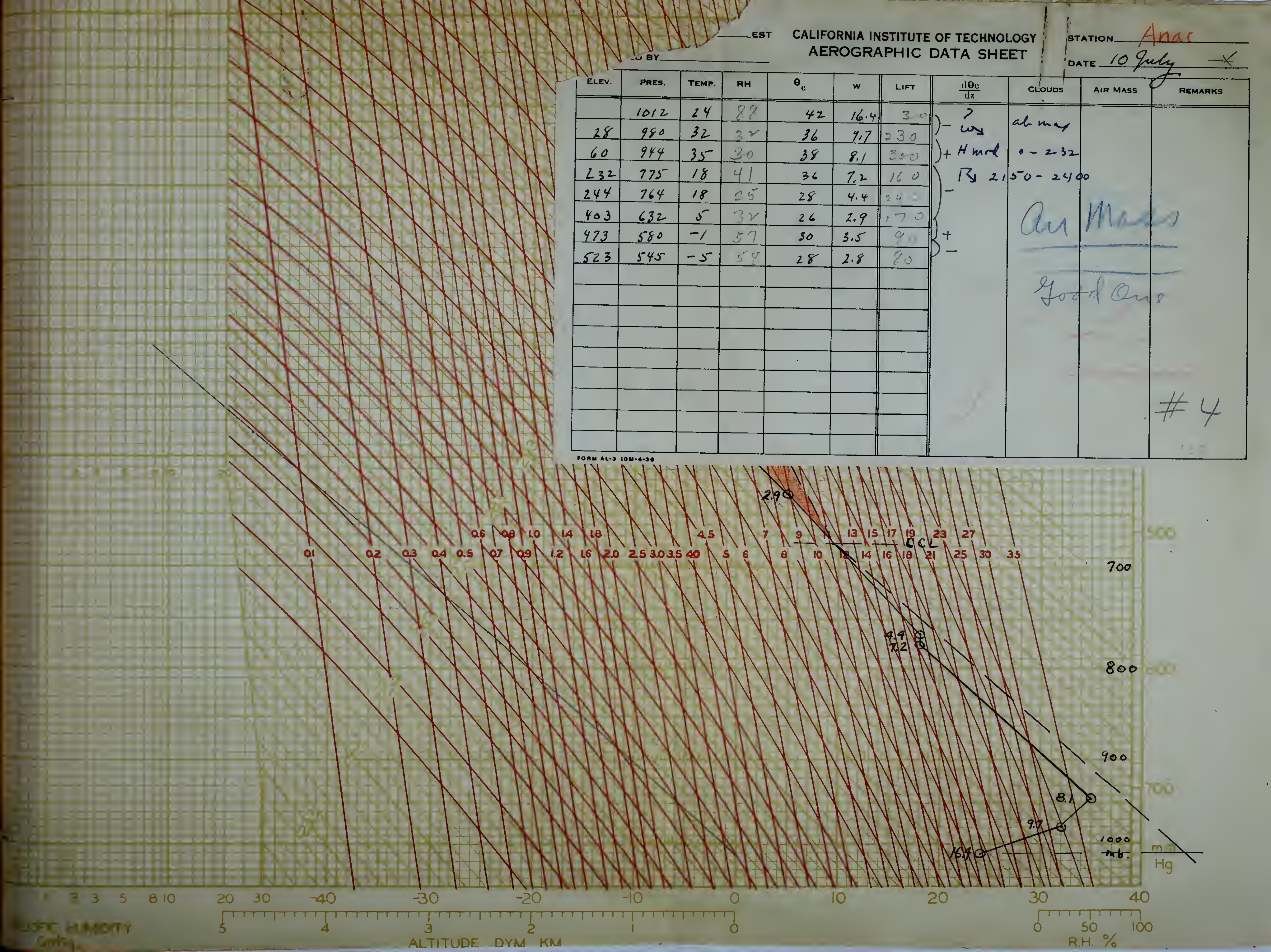
... BY ______

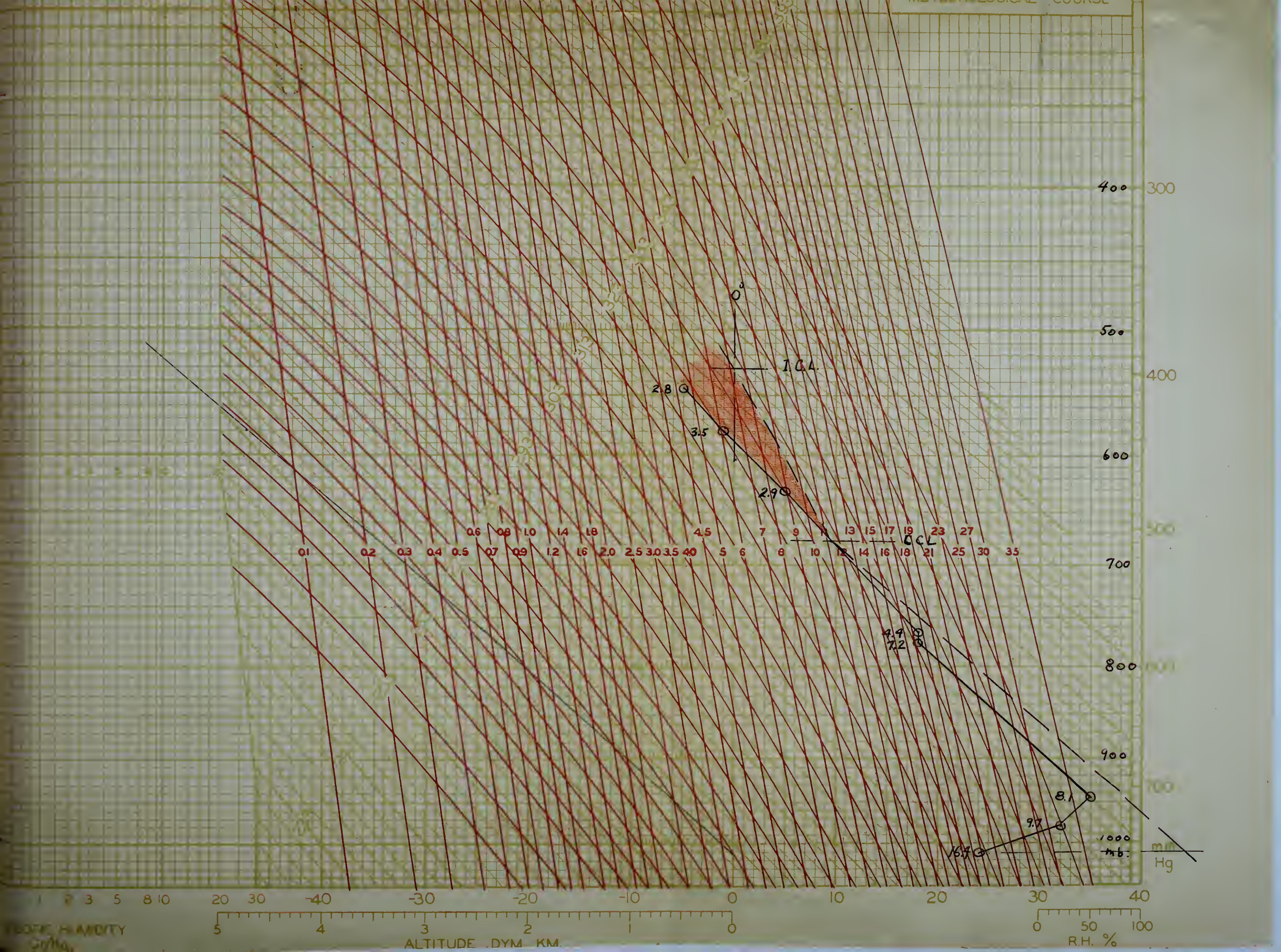
ELEV.	PRES.	TEMP.	RH	θ_c	W	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1012	24	88	42	16.4	30	?	ab may		
28	980	32	32	36	9.7	230	− ws			
60	944	35	30	38	8.1	300	+ H mrd	0 − 232		
232	775	18	41	36	7.2	160	Rs 2150 − 2400			
244	764	18	25	28	4.4	240	−			
403	632	5	32	26	2.9	170		Air Mass		
473	580	−1	57	30	3.5	90	+			
523	545	−5	58	28	2.8	80	−			

Good One

4

FORM AL-3 10M-4-36





I.C.L.
C.C.L.
2.8
3.5
2.9
4.4
7.2
8.1
9.7
16.4
400
500
600
700
800
900
1000 mb.
300
400
mm Hg
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.2 1.4 1.6 1.8 2.0 2.5 3.0 3.5 4.0 4.5 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 23 25 27 30 35
-40 -30 -20 -10 0 10 20 30 40
ALTITUDE DYM. KM.
5 4 3 2 1 0
R.H. %
0 50 100
SPECIFIC HUMIDITY

EXAMPLE # 5.

Lakehurst, New Jersey. 10 July, 1936.

This is type # 3, air mass thunderstorm situation.

This is a situation practically identical with that at Anacostia, Va. on the same day, example # 4. The only difference lies in the surface inversion being smaller and the mean specific humidity 2 grams per kilogram higher, 14 grams per kilogram in this case.

Here again the LCL is meaningless, due to the tremendous lift required, and attention is confined to the CCL.

The CCL is found to be at 744 millibars, 2650 meters. The maximum temperature required for free convection is found to be 40° C. This would seem excessive, but it was exceeded on this particular day. When the CCL is reached by convection due to insolational heating it is found that, following the moist adiabatic up from its intersection with the CCL, the area everywhere above that point will be positive. The ICL is very high, 513 millibars, 5580 meters, and the extrapolated aerograph curve above that point appears to be closing up the positive area. However, there will be accelerations on a particle for 2930 meters, from the CCL to the ICL and for an undetermined distance beyond. A thunderstorm should be predicted for the station.

A high level thunderstorm of slight intensity occurred near the station at 2100. No record of type or amount of precipitation.

TIME SOUNDING 0430 EST

CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

STATION Lakehurst, N. J.

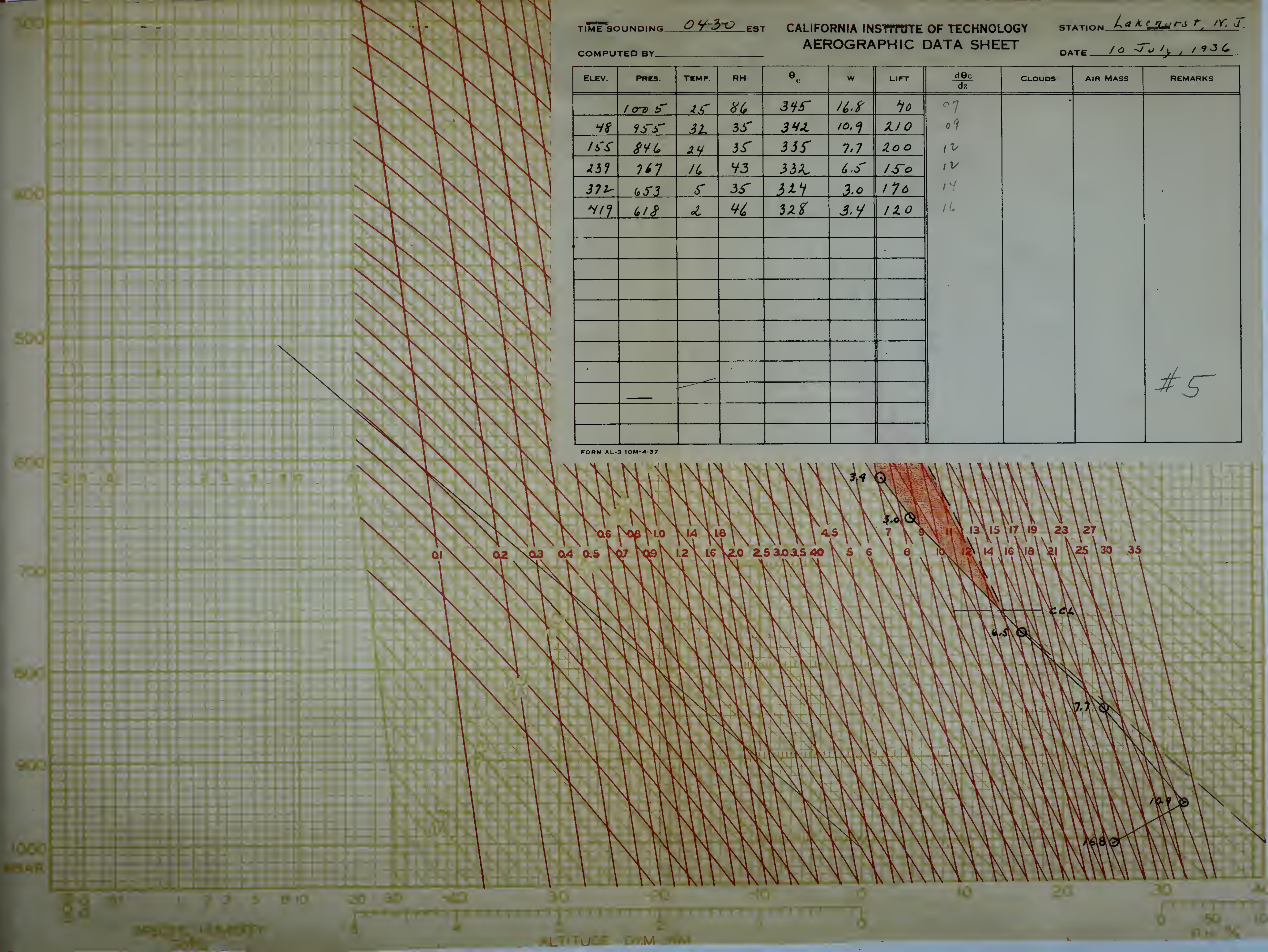
COMPUTED BY

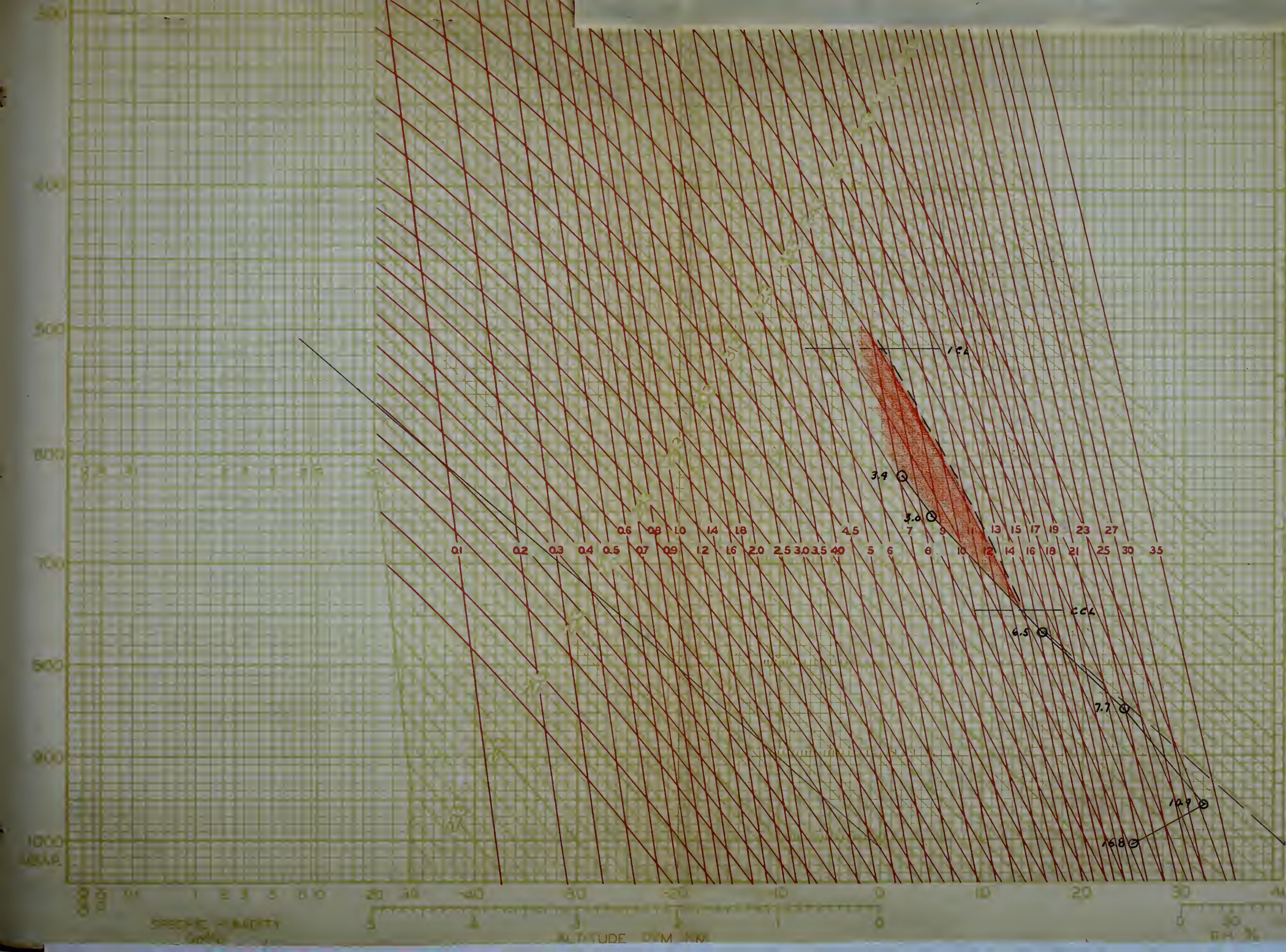
DATE 10 July, 1936

ELEV.	PRES.	TEMP.	RH	θ_e	w	LIFT	$\frac{d\theta_e}{dz}$	CLOUDS	AIR MASS	REMARKS
	1005	25	86	345	16.8	40	07			
48	955	32	35	342	10.9	210	09			
155	846	24	35	335	7.7	200	12			
239	767	16	43	332	6.5	150	12			
372	653	5	35	324	3.0	170	14			
419	618	2	46	328	3.4	120	16			

#5

FORM AL-3 10M-4-37





LCL
CCL
3.9
3.0
6.5
7.7
12.9
16.8
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.4
1.6
1.8
2.0
2.5
3.0
3.5
4.0
4.5
5
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35

EXAMPLE # 6.

Anacostia, Virginia. 11 July, 1936.

This is type # 3, air mass thunderstorm situation.

This and the following case, # 7, are introduced to indicate that under a given set of conditions, similar in the main points to those existing on the previous day, the same phenomena may be expected for both days.

The synoptic chart shows the forecaster that he will deal with but one air mass during the forecast period, T_{23}.

A mean value of specific humidity, 12 grams per kilogram, is chosen for the actual specific humidity of the particle to be lifted. It may be noted that the gradient of specific humidity has decreased from the previous day. The larger values aloft may be considered as due to mixing.

As before the LCL is without meaning. The CCL is found at 697 millibars, 3140 meters. The maximum temperature required for free convection is found to be 41° C. With practically the same conditions existing as on the previous day it may be assumed that this is not excessive.

When convections reach the CCL it is found that, following the moist adiabatic up from that point, the area everywhere above will be positive. The ICL is very high, 527 millibars, 5340 meters. A particle leaving the CCL will be continuously accelerated for 2200 meters to the ICL and for a distance beyond that point which cannot be estimated. A thunderstorm should be predicted for the station.

A thunderstorm occurred over the station at 1910.

EST

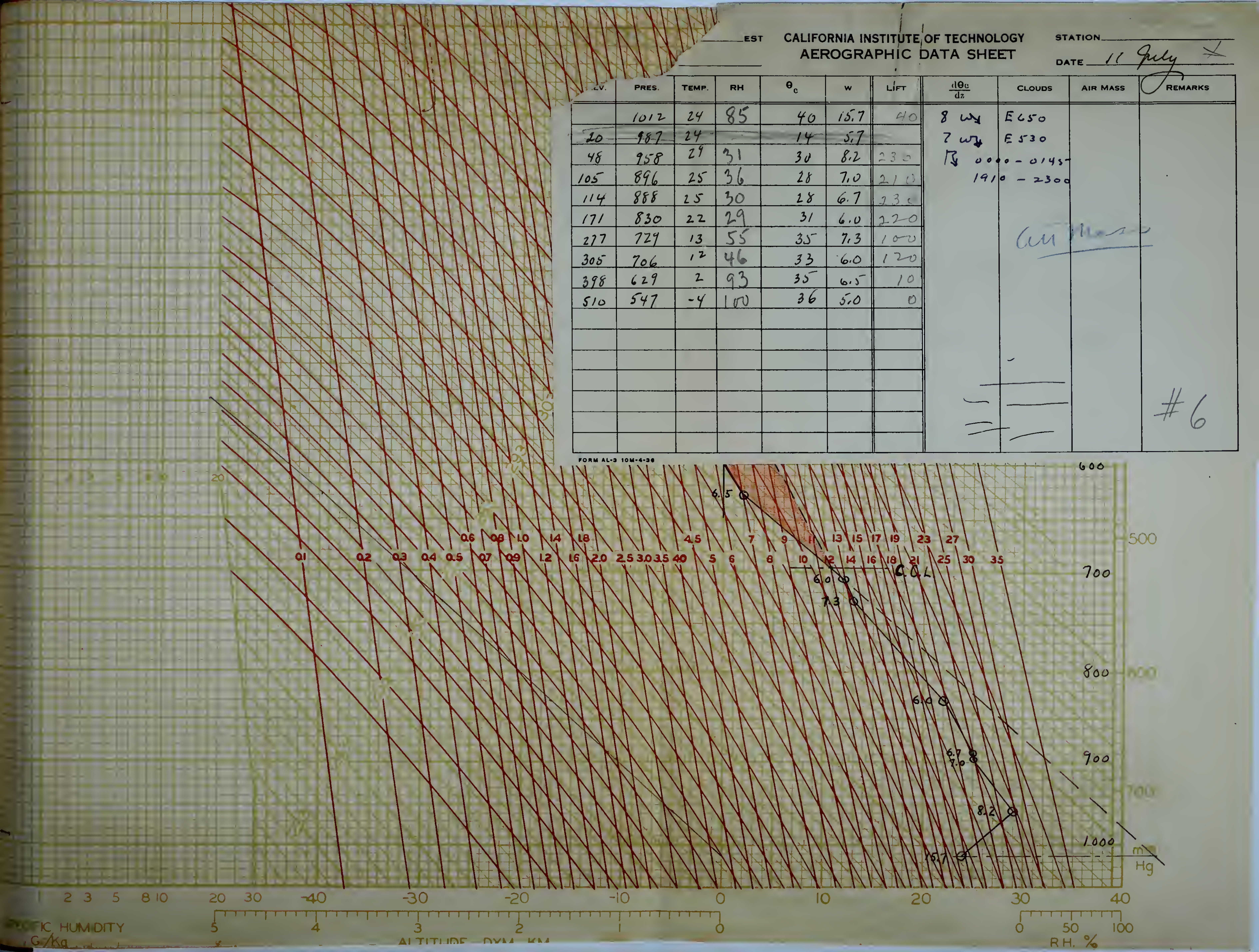
CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

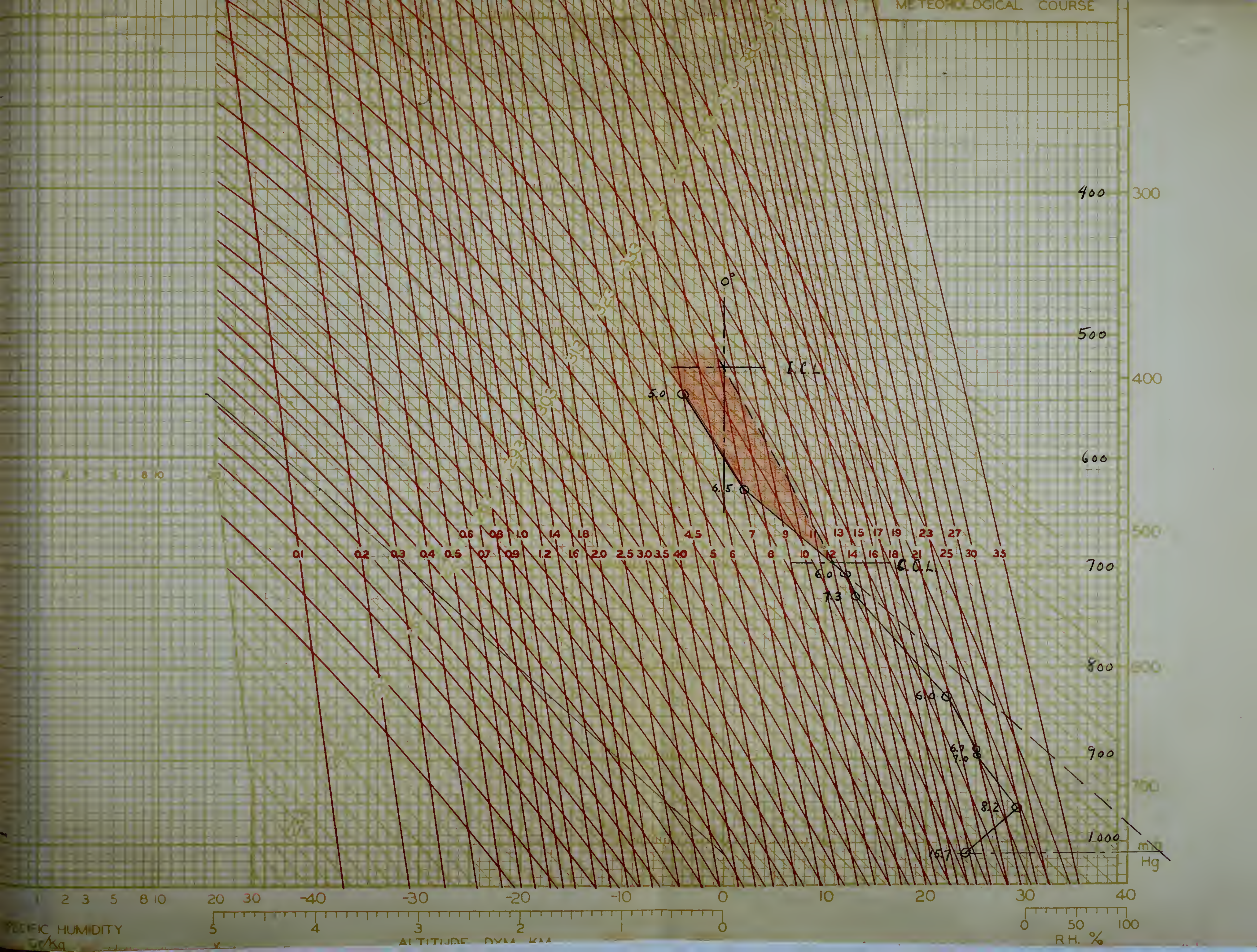
STATION

DATE 11 July

ELEV.	PRES.	TEMP.	RH	θ_c	w	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1012	24	85	40	15.7	40	8 wy	E650		
~~20~~	~~987~~	~~24~~		~~14~~	~~5.7~~		7 wy	E530		
48	958	29	31	30	8.2	230	R 0000 - 0145			
105	896	25	36	28	7.0	210	1910 - 2300			
114	888	25	30	28	6.7	230				
171	830	22	29	31	6.0	220				
277	729	13	55	35	7.3	100		Air Mass		
305	706	12	46	33	6.0	120				
398	629	2	93	35	6.5	10				
510	547	-4	100	36	5.0	0				
										#6

FORM AL-3 10M-4-36





METEOROLOGICAL COURSE
0°
I.C.L.
C.C.L.
5.0
6.5
6.0
7.3
6.0
6.7
7.0
8.2
15.7
400
500
600
700
800
900
1,000
300
400
500
600
700
mm Hg
SPECIFIC HUMIDITY Gr/Kg
ALTITUDE DYM KM
R.H. %

EXAMPLE # 7.

Lakehurst, New Jersey.   11 July, 1936.

This is type # 3, air mass thunderstorm situation.

This situation is practically identical with case #6.

The mean value of specific humidity, 15 grams per kilogram is chosen as the actual specific humidity of the particle to be lifted.

The CCL is found at 699 millibars, 3180 meters, and the maximum temperature required for free convection is 41°5 C. Again, considering the previous day this is not excessive.

When convections reach the CCL it is seen that, following up the moist adiabatic through this point, the area everywhere above will be positive. The ICL is very high, 506 millibars, 5700 meters. Convections which reach the CCL will be continuously accelerated from there for 2520 meters to the ICL and for a distance beyond that point which cannot be determined. A thunderstorm should be predicted for the station.

A high level thunderstorm of slight intensity occurred over the station at 2000. There was no record of type or amount of precipitation.

TIME SOUNDING 0501 EST

COMPUTED BY

CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

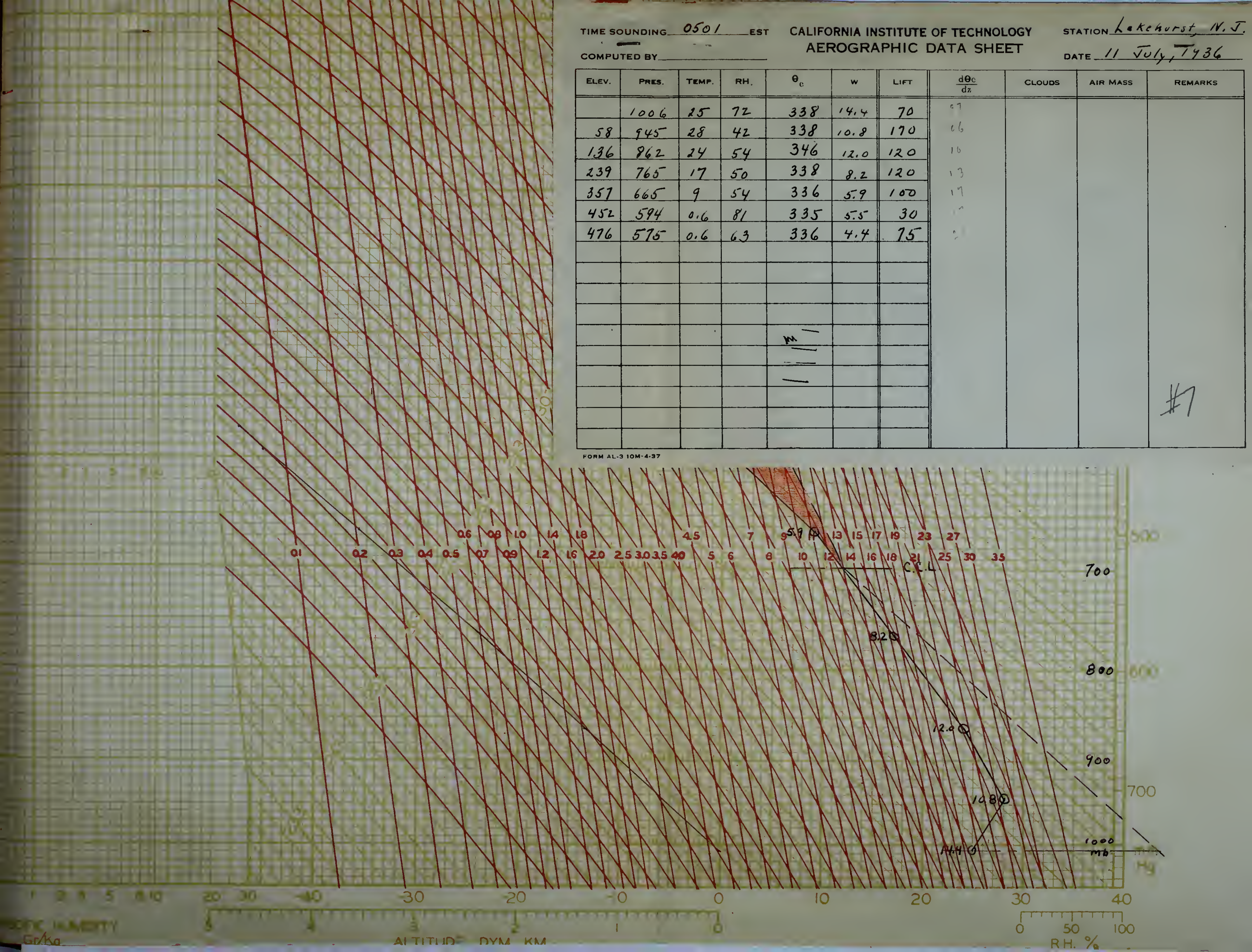
STATION Lakehurst, N.J.

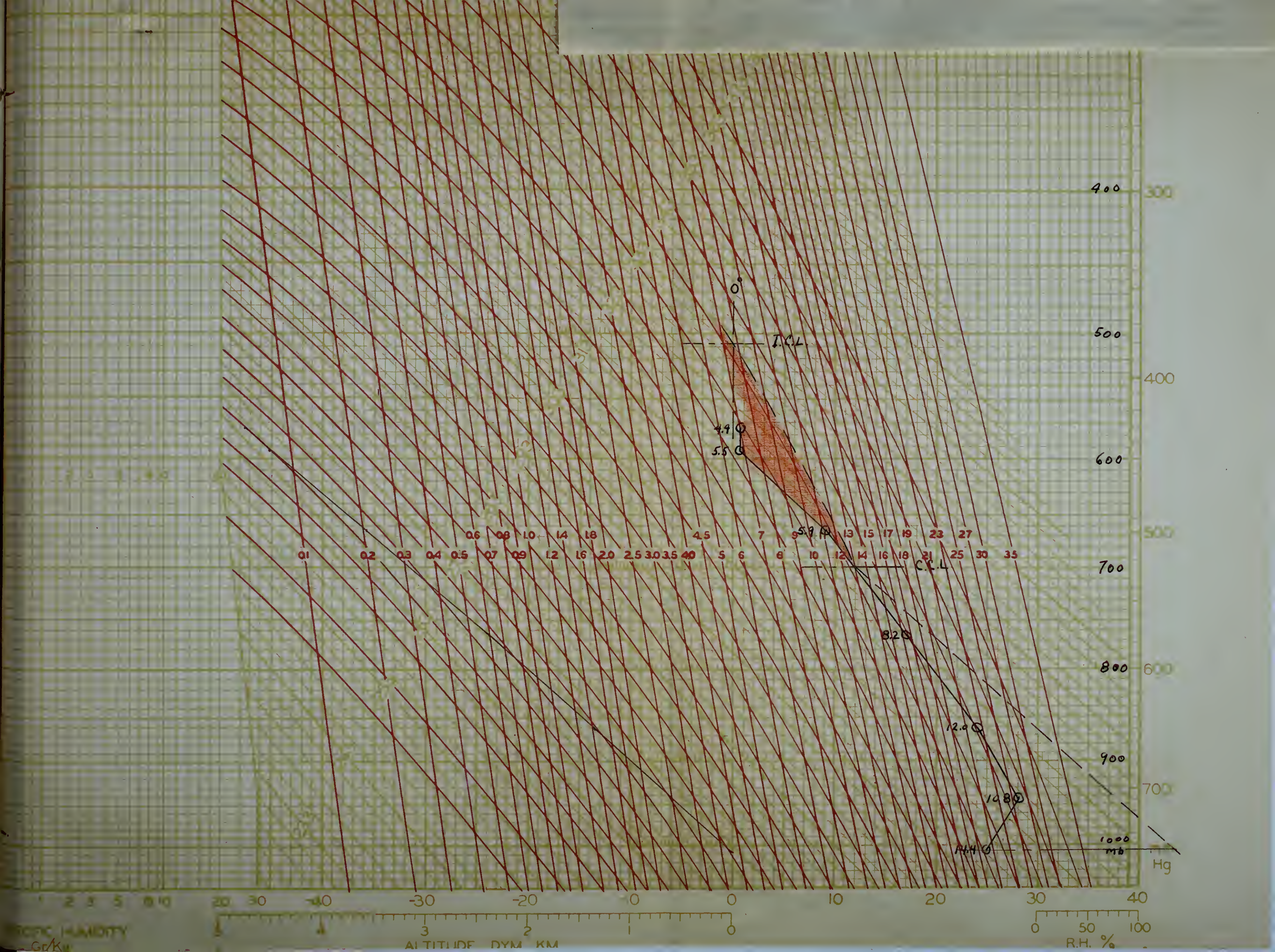
DATE 11 July, 1936

ELEV.	PRES.	TEMP.	RH.	θ_c	w	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1006	25	72	338	14.4	70	07			
58	945	28	42	338	10.8	170	06			
136	862	24	54	346	12.0	120	16			
239	765	17	50	338	8.2	120	13			
357	665	9	54	336	5.9	100	17			
452	594	0.6	81	335	5.5	30	[illegible]			
476	575	0.6	63	336	4.4	75	[illegible]			

#7

FORM AL-3 10M-4-37





0°
I.C.L
4.9
5.5
5.9
C.C.L
8.2
12.0
10.8
14.4
400
500
600
700
800
900
1000 mb
300
400
500
600
700
Hg
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.2 1.4 1.6 1.8 2.0 2.5 3.0 3.5 4.0 4.5 5 6 7 8 9 10 12 13 14 15 16 17 18 19 21 23 25 27 30 35
-40 -30 -20 -10 0 10 20 30 40
ALTITUDE DYM KM
R.H. %
0 50 100
SPECIFIC HUMIDITY Gr/Kg

EXAMPLE # 8.

San Diego, California. 4 December, 1936.

This is type # 3, air mass thunderstorm situation.

Consideration of the synoptic chart shows the forecaster that during the forecast period he will be dealing with only one air mass, $_4$Pp; and that the pressure should fall for some hours, due to an approaching trough.

The actual specific humidity of the surface point, 6.3 grams per kilogram, is chosen for the saturation specific humidity of the surface point to be lifted, either orographically or convectively.

Inspection of the adiabatic chart shows the LCL at 929 millibars, 720 meters. If the moist adiabatic is followed up from this point it will show a small negative, resistant, area to 780 millibars, 2150 meters. No possibility exists at this station for the mechanical lift required to set off free convection so attention is turned to the CCL.

The CCL is found to be at 872 millibars, 1250 meters, the maximum temperature required for free convection is 17° C. Inspection of the diurnal temperature curves for this station show that this temperature is not excessive for the date.

Following the moist adiabatic up from its intersection with the CCL it is found that it lies to the right of the aerograph curve from 872 millibars to 620 millibars, 3980 meters, and to the left of that curve from there to the end. This means that there will be accelerations on a particle

leaving the CCL for a distance of 1730 meters to the 620 millibar level, where it will enter a resistant stratum and be decellerated until upward velocity is completely halted at a point which cannot be determined due to the termination of the sounding. However, the ICL is at 779 millibars, 2150 meters, within the positive area. There will be accelerations on a particle leaving the CCL for 900 meters to the ICL and from there to the beginning of the resistant stratum, 830 meters further. Since it can be estimated that vertical velocities of some moment will extend for at least 2000 meters a thunderstorm should be predicted for the station. Light showers could very well be expected to accompany it, but certainly no hail.

The maximum required temperature of 17° C. was reached at 1100 at San Diego and a thunderstorm of slight intensity accompanied by light showers occurred over the station at 1240.

Although it was not needed to indicate thunderstorm possibilities, the fact that a decrease of pressure was indicated for the station would have suggested a probable increase in the instability of the ascent curve due to the development of convergence. Had the case been border line this should have lent weight to a decision to forecast thunderstorm conditions.

SOUNDING: 0610 P.S.T. ~~EST~~

CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

STATION N.A.S. San Diego.

COMPUTED BY

DATE 4 December 1936

ELEV. meters	PRES. mb	TEMP. C°	RH %	θ_c	w	LIFT meters	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
0	1012	13.1	69	303	6.3	700		8-StCu-SSW		
357	973	11.9	68	304	6.1	700				
627	941	9.4	75	304	6.0	500				
1274	871	4.5	72	305	4.4	600				
2489	749	-4.1	83	303	3.1	300				
3004	701	-4.8	65	304	2.5					
3667	645	-10.1	63	304	1.6					
4182	603	-12.1	52	306	1.2					
5141	532	-19.1	43	307	0.6					

StCu at 2600 feet. Patches of St. on mountain tops. Scattered showers in all directions. Base StCu ragged from 5400 to 6200 feet. Tops from 6900 to 7800 feet. Scattered StCu with few breaks in all directions to limits of visibility.

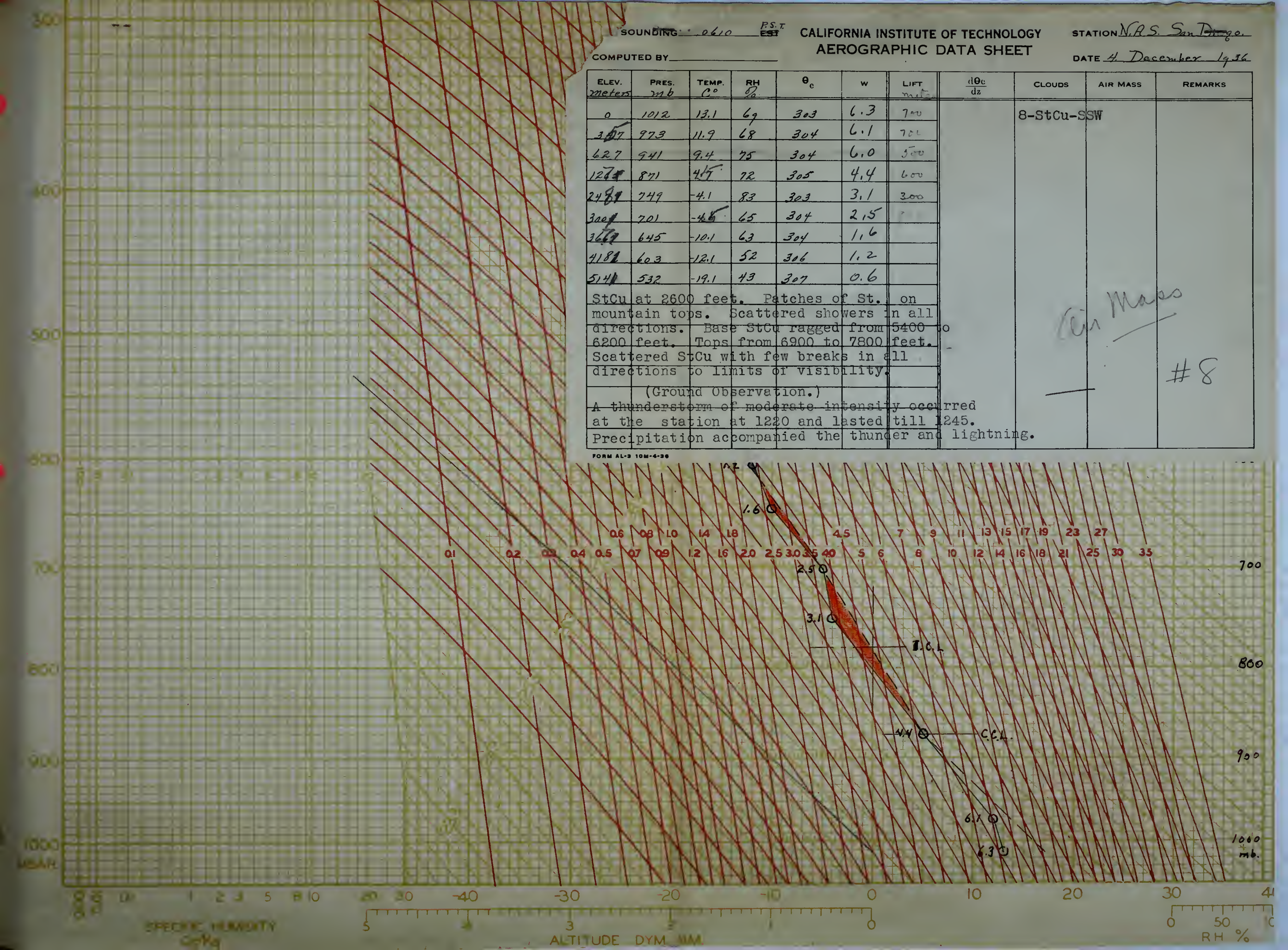
(Ground Observation.)

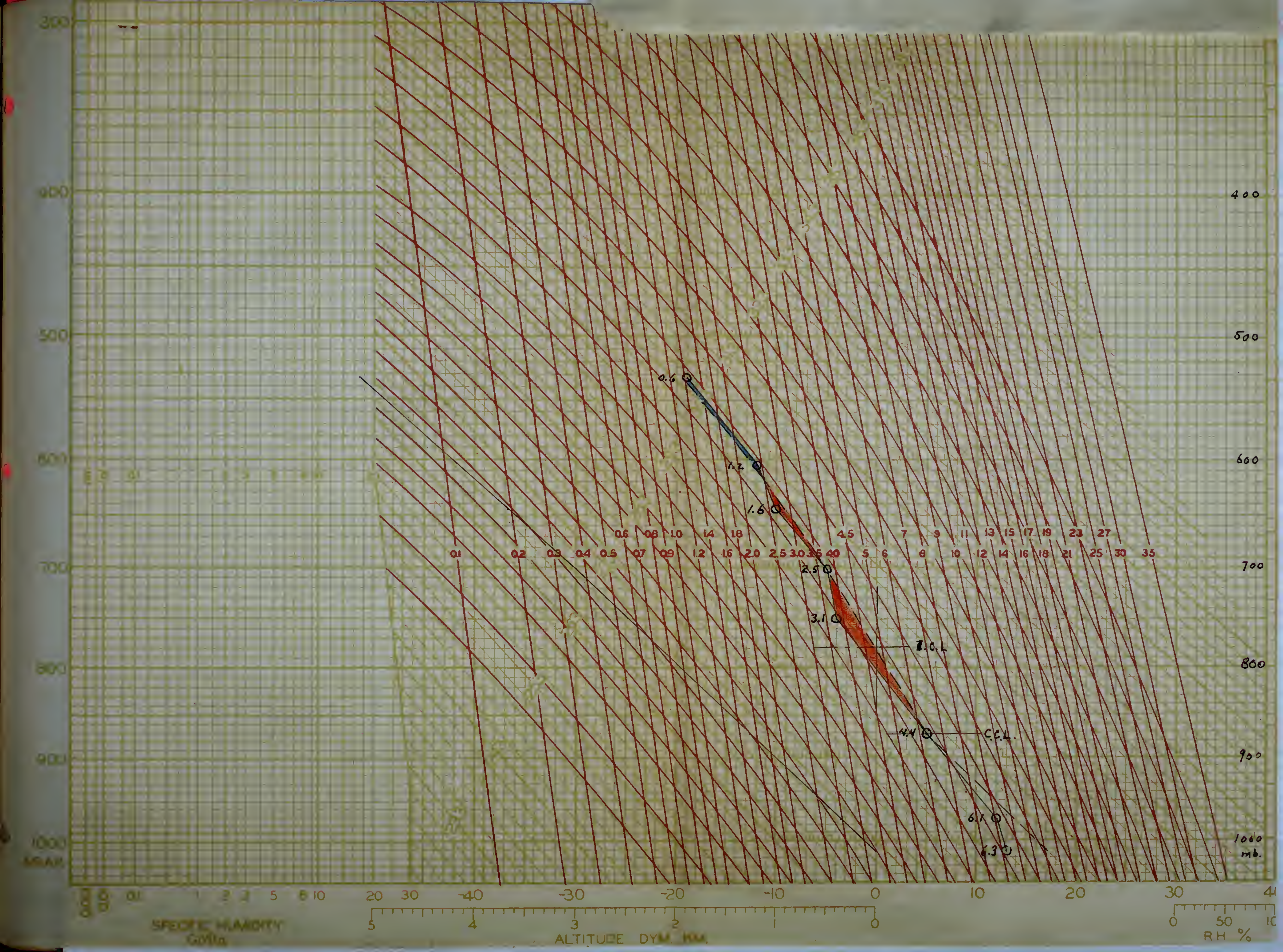
~~A thunderstorm of moderate intensity occurred~~ at the station at 1220 and lasted till 1245. Precipitation accompanied the thunder and lightning.

Air Mass

#8

FORM AL-3 10M-4-36




0.6
1.2
1.6
2.5
3.1
L.C.L
4.4
C.C.L.
6.1
6.3
400
500
600
700
800
900
1000 mb.
SPECIFIC HUMIDITY
ALTITUDE DYM. KM.
RH %

EXAMPLE # 9.

Pasadena, California. 22 March, 1937.

This is type # 4, air mass thunderstorm situation.

The synoptic chart shows the forecaster that he will deal with but one air mass, $_{S}Pp_{1}$, during the forecast period.

The saturation specific humidity, 7.4 grams per kilogram, is chosen as the actual specific humidity of the surface particle to be lifted, either orographically or by convection, since the station is near the seacoast and there is no inversion.

Inspection of the adiabatic chart shows that the LCL is at 970 millibars, 840 meters, as is the CCL. A moist adiabatic followed up from this point will show everywhere a positive area. The elevation of Pasadena is not sufficent to provide the lift required for free convection, hills nearby in the path of the flow are high enough, though in this case lift was not necessary for insolational heating set off the convections before the air had reached the hills. The CCL indicates that a maximum temperature of 12° C. is required to establish free convection. This temperature was reached at about the time the aerograph sounding, from San Diego, California, was made. Convections had already started when the air reached this station.

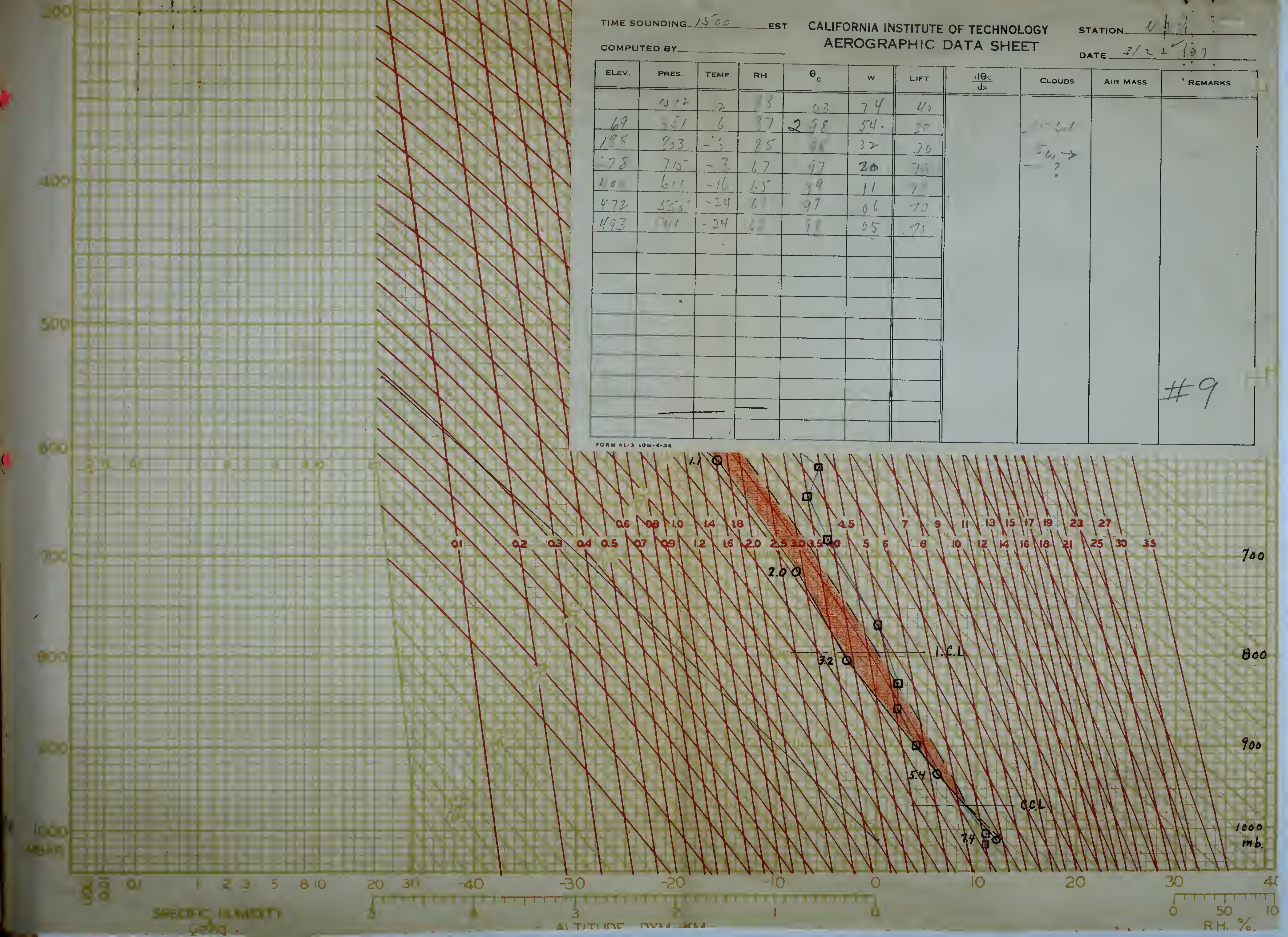
Convections will cause a rising particle to be accelerated for 1690 meters to the ICL, which is seen to be at 797 millibars, 1930 meters, and for several thousand meters

above that point. Extrapolation of the ascent curve indicates a closing of the positive area somewhat above 5000 meters.

In this case, since the ICL is so low, the probability of violent electrical phenomena is remote, but the forecaster would certainly be justified in predicting hail accompanied by a light thunderstorm for the station.

A light thunderstorm accompanied by considerable hail and rain showers occurred at this station at 1245.

The ascent curve for the following day has been added to point out the stabilizing effect of subsidence, which has rendered the same air mass, violently unstable one day, stable on the following. From this curve one could predict a few strato-cumulus with bases at 950 millibars, 500 meters, and tops cut off by the stable layer at 830 millibars, 1690 meters.



TIME SOUNDING 1500 EST

COMPUTED BY

CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

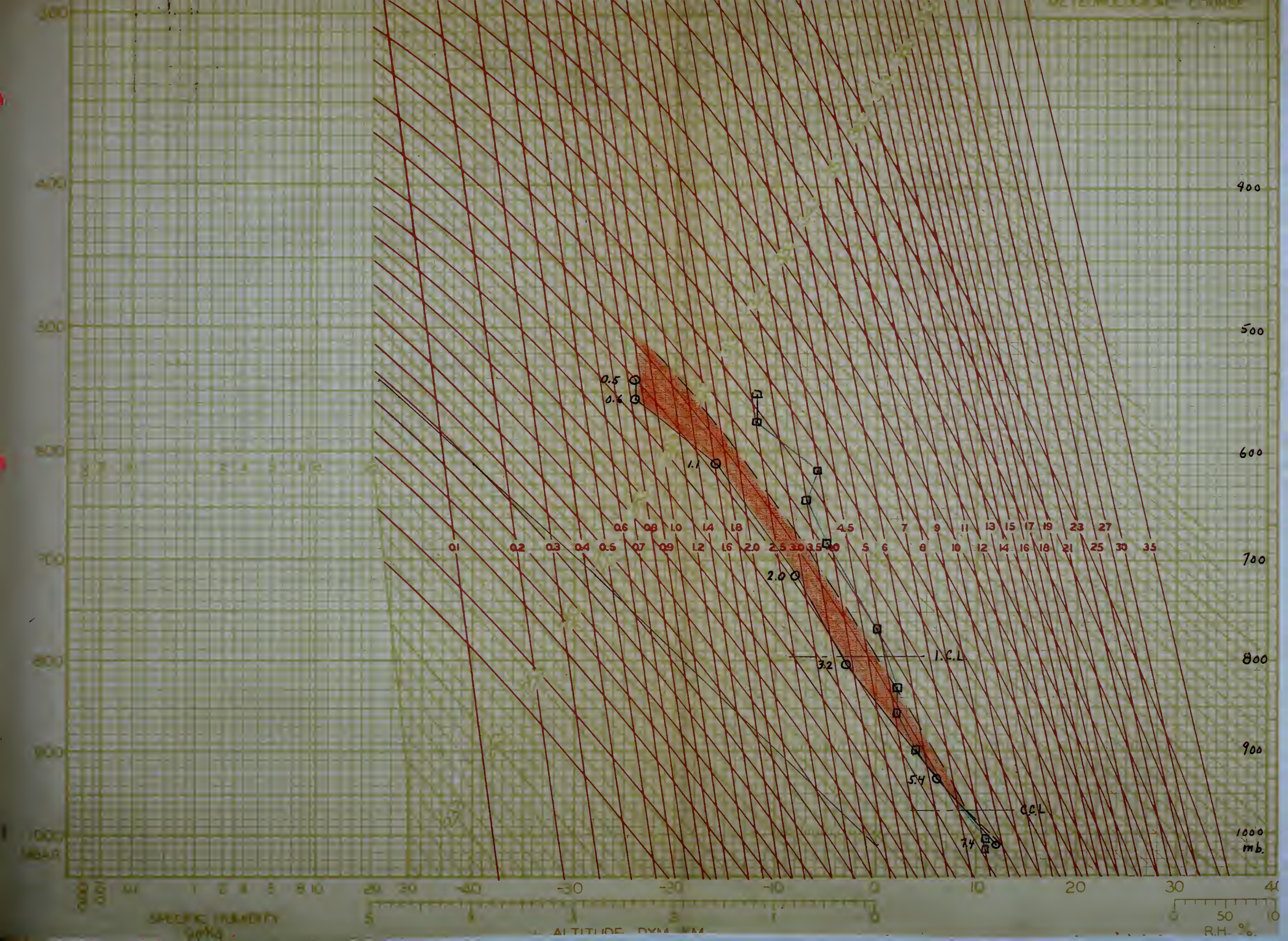
STATION [illegible]

DATE 3/22/37

ELEV.	PRES.	TEMP.	RH	θ_c	W	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1012	2	83	03	74	40				
69	931	6	37	298	54.	20		[illegible]		
188	853	-3	85	98	32	30		Sw →		
278	715	-3	67	97	20	70		?		
400	611	-16	15	99	11	7				
472	555	-24	6[illegible]	97	66	70				
493	[illegible]	-24	[illegible]	[illegible]	05	71				

#9

FORM AL-3 10M-4-34



0.5
0.6
1.1
2.0
3.2
5.4
7.4
I.C.L
C.C.L
400
500
600
700
800
900
1000
mb.
SPECIFIC HUMIDITY
ALTITUDE
R.H. %

EXAMPLE # 10.

Pasadena, California.   16 March, 1937.

This is type # 3, air mass thunderstorm situation.

Consideration of the synoptic chart shows the forecaster that during the forecast period he will be dealing with only one air mass, Pp.

From the adiabatic chart it is found that, within the accuracy of instruments and chart, the surface layer to 200 meters is saturated, at 10 grams per kilogram.

Convections due to insolational heating will cause the surface particle to run immediately into a resistant layer which extends to 692 millibars, 3060 meters. The diurnal temperature curves indicate that the maximum temperature to be reached during the day will not be sufficent to provide free convection.

Turning to the effects of lifting it is seen that a lift of 200 meters will so change the structure of the aerograph curve that any further lifting will result in free convection with the development of a positive area. This is shown in the curve marked in green. Since the height of Pasadena will not give the lift required for free convection no thunderstorm need be anticipated at the station.

However, the flow of air is from the west and nearby to the east of Pasadena lie hills which will provide more than enough lift to set off convective action. Since the positive area which will be developed by lift contains the ICL at

EXAMPLE # 10.

Pasadena, California.   14 March, 1937.

This is type # 3, air mass thunderstorm situation.

Consideration of the synoptic chart shows the forecaster that during the forecast period he will be dealing with only one air mass, Tp.

From the adiabatic chart it is found that, within the accuracy of instruments and chart, the surface layer to 200 meters is saturated, at 10 grams per kilogram.

Convections due to insolational heating will cause the surface particle to run immediately into a resistant layer which extends to 688 millibars, 3250 meters. The diurnal temperature curves indicate that the maximum temperature to be reached during the day will not be sufficient to provide free convection.

Turning to the effects of lifting it is seen that a lift of 200 meters will so change the structure of the aerograph curve that any further lifting will result in free convection with the development of a positive area. This is shown in the curve marked in green. Since the height of Pasadena will not give the lift required for free convection no thunderstorms need be anticipated at the station.

However, the flow of air is from the west and nearby to the east of Pasadena lie hills which will provide more than enough lift to set off convective action. Since the positive area which will be developed by lift contains the LCL at

720 millibars, 2740 meters, and extends for some undetermined distance beyond the top of the ascent curve, a thunderstorm should be expected to occur in the mountains close to Pasadena.

The day was clear at Pasadena but thunderstorms accompanied by light showers occurred in the hills just to the east, starting at 1710. An increase in the intensity was reported as the air continued its flow into the higher area still further to the east.

TIME SOUNDING 10 EST CALIFORNIA INSTITUTE OF TECHNOLOGY STATION NNI

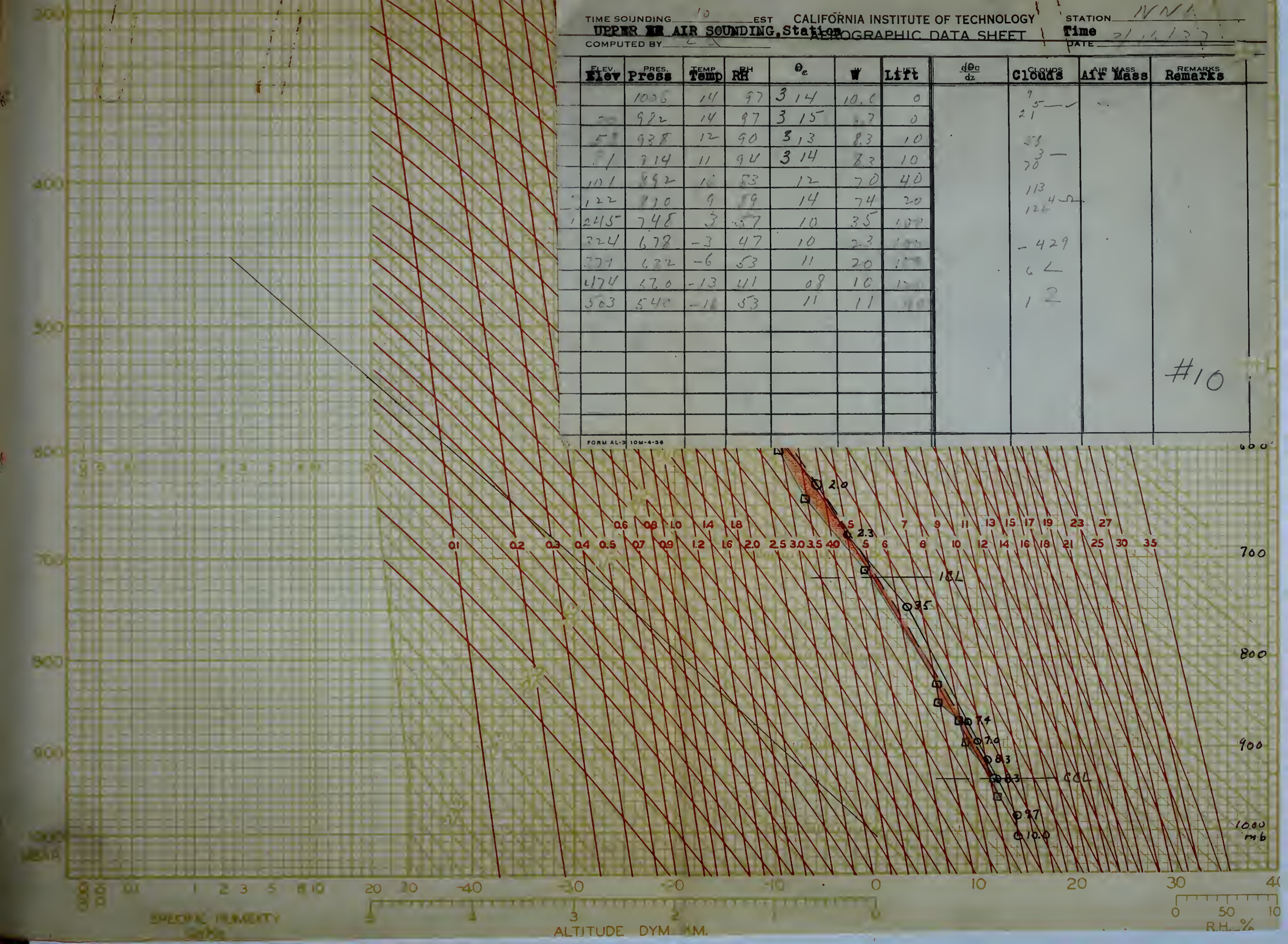
UPPER AIR SOUNDING, Station AEROGRAPHIC DATA SHEET Time 21/1/37

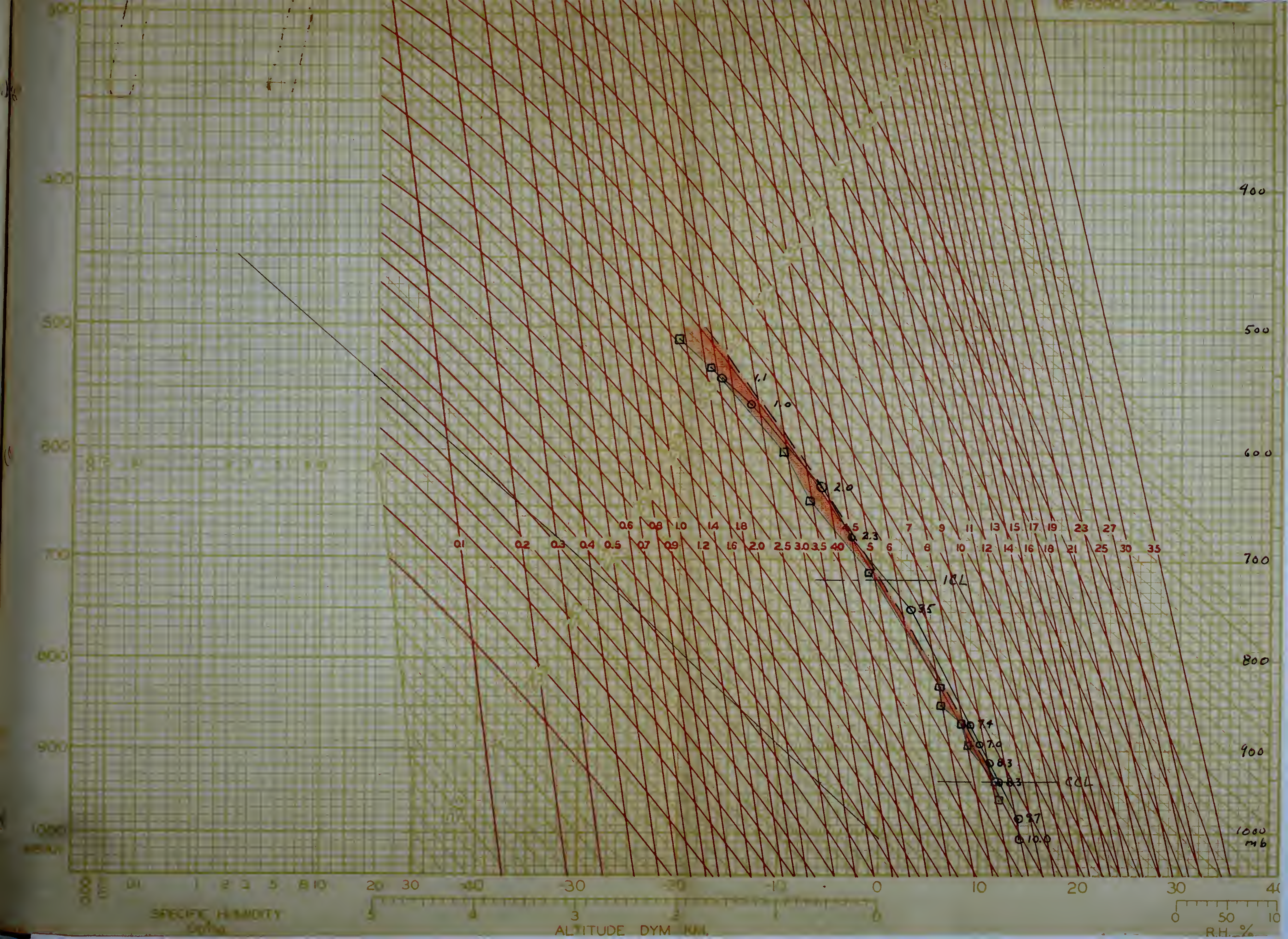
COMPUTED BY [illegible] DATE

Elev	Press	Temp	RH	θ_e	W	Lift	$\frac{d\theta_e}{dz}$	Clouds	Air Mass	Remarks
	1006	14	97	314	10.0	0		9 5 — 21		
[illegible]	982	14	97	315	[illegible].7	0				
51	938	12	90	3,3	8.3	10		53		
[illegible]1	914	11	94	314	8.3	10		3 — 70		
101	892	1[illegible]	83	12	70	40		113		
122	810	9	59	14	74	20		4 — 124		
245	748	3	57	10	35	[illegible]				
324	678	-3	47	10	23	[illegible]		– 429		
371	632	-6	53	11	20	[illegible]		6		
474	570	-13	41	08	10	[illegible]				
503	540	-1[illegible]	53	11	11	[illegible]		1 2		

#10

FORM AL-3 10M-4-36





METEOROLOGICAL COURSE
400
500
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0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.2 1.4 1.6 1.8 2.0 2.5 3.0 3.5 4.0 4.5 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 23 25 27 30 35
1.1
1.0
2.0
2.3
ICL
3.5
7.4
7.0
8.3
CCL
9.7
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1000 mb
-40 -30 -20 -10 0 10 20 30 40
SPECIFIC HUMIDITY
ALTITUDE DYM KM
R.H. %

SECTION TWO

FRONTAL THUNDERSTORMS

Under this category are included those thunderstorms occurring in the presence of, and due to, frontal activity. This type may occur at any time of the year but is most frequently observed during the warm months. They may occur in almost every combination of air masses but due to the typical structure of conditional instability and large moisture content inherent in Tg and Ta air masses, thunderstorms will most frequently be found where this air forms the warm sector of a frontal disturbance.

Frontal thunderstorms are nearly identical in the mechanics of formation to the orographical air mass type. This may be readily seen when one considers the trajectories of air in the warm sector of a front. In the case of warm front thunderstorms the warm air is lifted by its ascent over the cold air which it is over-running, this in itself is exactly analagous to an orographic obstruction. In addition to the effects of lifting there is a certain amount of divergent flow everywhere present except near the center of low pressure. Here it should be pointed out that divergence will increase the stability of any stable layer, counteracted in some measure by the effects of lifting, but it will increase the instability of an unstable layer adding its increase of instability to that furnished by lifting after saturation.

Further, in the discussion of warm front thunderstorms, the possibility of thunderstorms occurring in the cold air

beneath the over-running warm air, in addition to those in the warm air above, must be mentioned. There are several reasons why this may be (probable) usually a strong field of convergence due to an isallobaric low can be found in the cold air which would reduce the stability of what is usually a returning polar mass in advance of the warm front. In summer, too, the fact that a warm front cloud system is much less complete than in winter would allow a greater amount of insolational heating through to produce convections in the colder mass. Such thunderstorms are not violent and are not often encountered.

In the case of cold front thunderstorms the mechanics of formation are again analogous to orographic lifting. The cold front intruding into the warm sector causes a lifting of the warm air, with greater vertical velocities than in the case of warm front over-running, and initiates this lifting some distance in advance of its position on the surface. For this reason it is usually found that there will be a formidable row of thunderstorms in the warm sector, just in advance of the surface position of a rapidly moving cold front. This type of thunderstorm is the most violent and destructive. In the case of slower moving cold fronts the position of the thunderstorm activity will vary and may be found, in some cases, close behind the surface position of the cold front.

An interesting phenomenon in this connection is the thunderstorm which results from a slow moving or stationary warm front that is turned into a cold front. The normal vertical

velocities of the over-running warm air will suddenly be given an additional impulse by the intrusion of cold air. Stations in the warm air, near the surface position of the front, whose soundings had indicated them safely out of thunderstorm activity may find that, with the change in direction of motion the slope of the front will be increased, additional vertical velocities will be given the warm air and, thereby, a frequently unexpected cold front thunderstorm will be initiated. Thus thunderstorms occurring 100 to 200 miles in advance of a slow moving warm front surface position will retreat to a position some miles in advance of what is now a cold front. Cold front situation # 7, in this section, gives an example of such an occurrence.

In this section several examples of both warm and cold front thunderstorms are presented, with a brief description of what appear to be the salient features of each.

velocities of the over-running warm air will suddenly be given an additional impulse by the intrusion of cold air. Stations in the warm air, near the surface position of the front, whose soundings had indicated them safely out of thunderstorm activity may find that, with the change in direction of motion the slope of the front will be increased, additional vertical velocities will be given the warm air and, thereby, a frequently unexpected warm front thunderstorm will be initiated. Thus thunderstorms occurring 100 to 200 miles in advance of a slow moving warm front surface position will retreat to a position some miles in advance of what is now a cold front. Cold front situation # 7, in this section, gives an example of such an occurrence.

In this section several examples of both warm and cold front thunderstorms are presented, with a brief description of what appear to be the salient features of each.

EXAMPLE # 1.

Pensacola, Florida. 18 January, 1936.

This is type # 5, cold front thunderstorm situation.

The synoptic chart shows a cold front approaching the station from the northwest, distant about 100 miles, on the morning of 18 January. The front is decellerating but should pass the station during the afternoon. The air masses involved are T_g at the station and the approaching mass, Pc_3.

From the aerograph sounding, plotted on an adiabatic chart, it may be seen that the air mass now overlying the station is conditionally unstable from 986 millibars, 240 meters to 703 millibars, 3070 meters.

It can readily be seen that convections due to insolational heating need not be anticipated. The interest of the forecaster is then turned to the amount of lift which will be required to release the potential instability of the T_g air. It is apparent from the chart that a lift of 500 meters will saturate the air from the surface to 2560 meters with the exception of a layer at 1900 meters which will be within a few tenths of a gram of saturation. The effect of convergence, discussed earlier, should certainly overcome this small difficulty. It is possible then to conclude that a lift of anything over 500 meters will be enough to release the potential instability of the air over the station.

If the salient points of the original ascent curve are each lifted 500 meters, remembering that some will ascend the moist adiabatic, some the dry, and some will follow first the

EXAMPLE # 1.

Pensacola, Florida. 13 January, 1931.

This is type # 5, cold front thunderstorm situation.

The synoptic chart shows a cold front approaching the station from the northwest, distant about 100 miles, on the morning of 13 January. The front is decelerating but should pass the station during the afternoon. The air masses involved are Tg at the station and the approaching mass, NPc.

From the aerograph sounding, plotted on an adiabatic chart, it may be seen that the air mass now overlying the station is conditionally unstable from 992 millibars, 100 meters to 795 millibars, 2070 meters.

It can readily be seen that convection due to insolational heating need not be anticipated. The interest of the forecaster is then turned to the amount of lift which will be required to release the potential instability of the Tg air. It is apparent from the chart that a lift of 500 meters will saturate the air from the surface to 2050 meters with the exception of a layer at 1800 meters which will be within a few tenths of a gram of saturation. The effect of convergence, discussed earlier, should certainly overcome this small difficulty. It is possible then to conclude that a lift of anything over 500 meters will be enough to release the potential instability of the air over the station.

If the salient points of the original ascent curve are each lifted 500 meters, remembering that some will ascend the moist adiabatic, some the dry, and some will follow first the

dry and then the moist adiabatic for part of the distance, curve # 2 will be obtained.

Inspection of this curve shows that further lifting will result in the particle which has reached 928 millibars, 740 meters, after lifting from 986 millibars, 240 meters, ascending the moist adiabatic through that point. From there upwards it will everywhere be warmer than its surroundings and will be continuously accelerated. There will be a positive area from 928 millibars, 740 meters, to the top of the ascent curve. The ICL is contained within this area at 590 millibars, 4470 meters.

The forecaster may conclude that with a lift of anything over 500 meters, certainly to be expected from the approaching front, there will be free convection extending from 740 meters, with continuous accelerations from there to the ICL at 4470 meters and increasing beyond that point for a distance which cannot be estimated. He should predict a thunderstorm, accompanied by moderate rain and hail, for the station during the first forecast period.

A thunderstorm occurred over the station at 1135, the front passed the station at 1500 with a rapid drop in temperature of 18° C. Unfortunately there is no report of the type of precipitation.

TIME SOUNDING .0800 EST

COMPUTED BY

CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

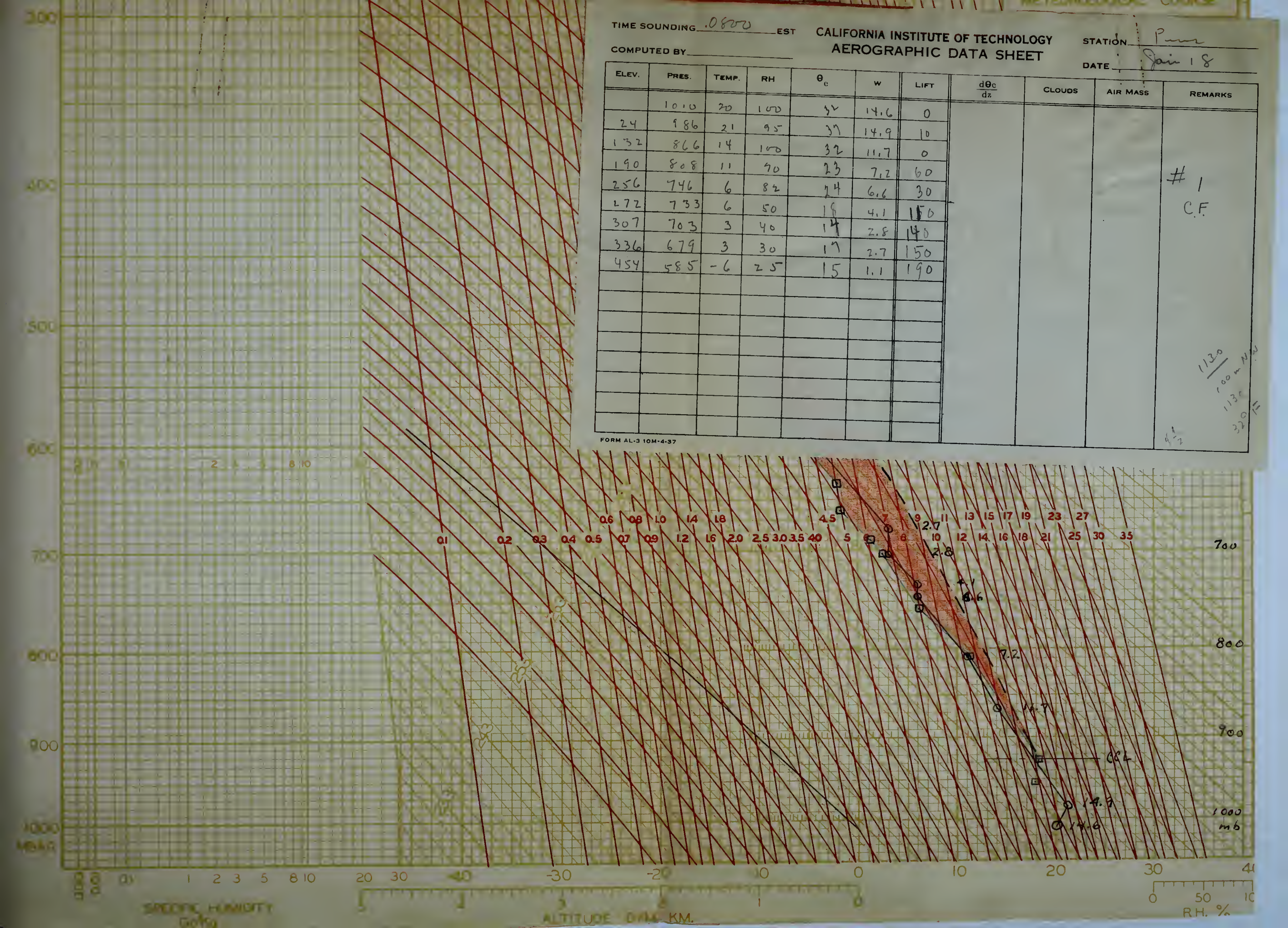
STATION Pom

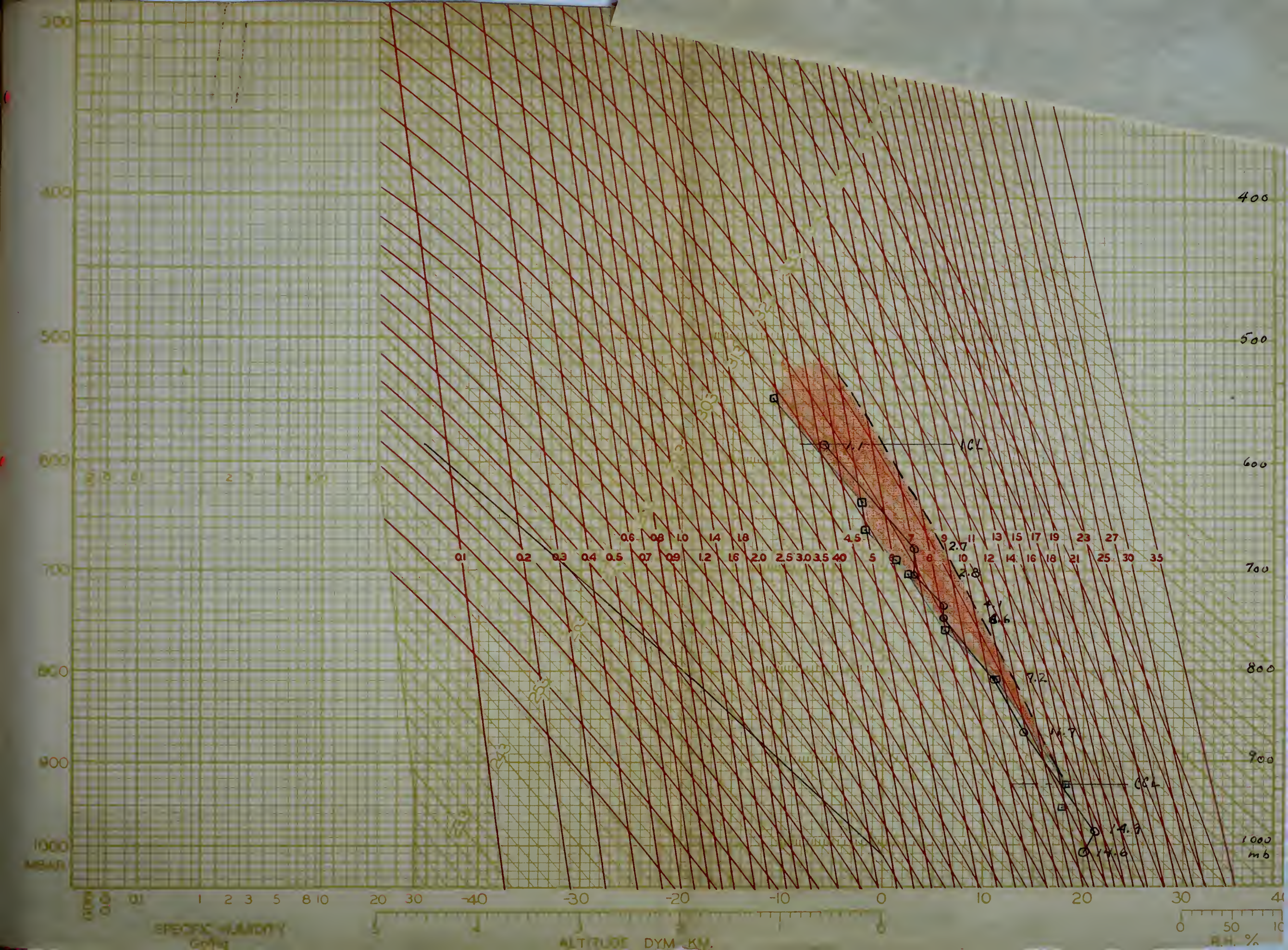
DATE Jan 18

ELEV.	PRES.	TEMP.	RH	θ_c	W	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1010	20	100	32	14.6	0				
24	986	21	95	37	14.9	10				
132	866	14	100	32	11.7	0				
190	808	11	90	23	7.2	60				
256	746	6	82	24	6.6	30				# 1
272	733	6	50	18	4.1	150				C.F.
307	703	3	40	14	2.8	140				
336	679	3	30	17	2.7	150				
454	585	-6	25	15	1.1	190				

1130
100 m NW
1130

FORM AL-3 10M-4-37





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1000 mb
CCL
ICL
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4.6
7.2
11.7
14.7
14.6
SPECIFIC HUMIDITY
ALTITUDE DYM KM.
R.H. %

EXAMPLE # 2.

Pensacola, Florida. 8 June, 1936.

This is type # 5, cold front thunderstorm situation.

The synoptic chart for the morning of 8 June shows a quasi-stationary front to the northeast of the station with a wedge of high pressure to the north. Such motion as the front has experienced has been generally toward the southwest, east of the station, and north to the west. The air masses involved are Tg, oPp and Pc_4.

From the aerograph curve, plotted on the adiabatic chart, it may be seen that the air mass overlying the station is conditionally unstable, in effect, throughout. There are small stable strata, but in the main the mass is conditionally unstable.

Examination of the chart shows the CCL, using 17 grams per kilogram as the actual specific humidity of the surface particle, to be at 884 millibars, 1220 meters. A maximum temperature of 31°5 C. is required for convection to reach that level. The diurnal temperature curves indicate that this will probably not be reached during the day so attention is given to the LCL. If certainty existed that there would be no frontal activity near the station the fact that the LCL is found to be at 958 millibars, 540 meters, would indicate that no further thought of thunderstorms need be in the forecasters mind. However, in view of the front near the station and the possibility of development of movement thereon it would be well to find what lifting would do to the air mass structure.

If the salient points of the original ascent curve are lifted 1000 meters, a reasonable lift considering frontal activity, curve # 2 will be obtained.

Inspection of this curve shows that further lifting will result in the particle which has reached 890 millibars, 1180 meters, after lifting from 998 millibars, 163 meters, ascending the moist adiabatic through that point. From there upward it will be warmer than its surroundings and will be continuously accelerated. So with further lifting there will be a positive area extending from 890 millibars, 1180 meters to the top of the ascent curve. The ICL is contained within this area at 542 millibars, 5220 meters.

The forecaster may conclude that in the case of regeneration of frontal activity and approach to his station, he will have the probability of free convections extending from 1180 meters, with continuous accelerations, to the ICL at 5220 meters and for a distance beyond that point which cannot be estimated. He should carefully watch his teletype reports, if available, and be prepared to give a supplementary forecast of moderate thunderstorm, accompanied by rain and hail, for the station if the front approaches.

In this case regeneration of the front occurred, motion toward the southwest was rapid, and a moderate thunderstorm passed over the station at 1610. Gusts of 51 knots were recorded during the thunderstorm but unfortunately the type of precipitation was not reported.

TIME SOUNDING ____________ EST

COMPUTED BY ____________

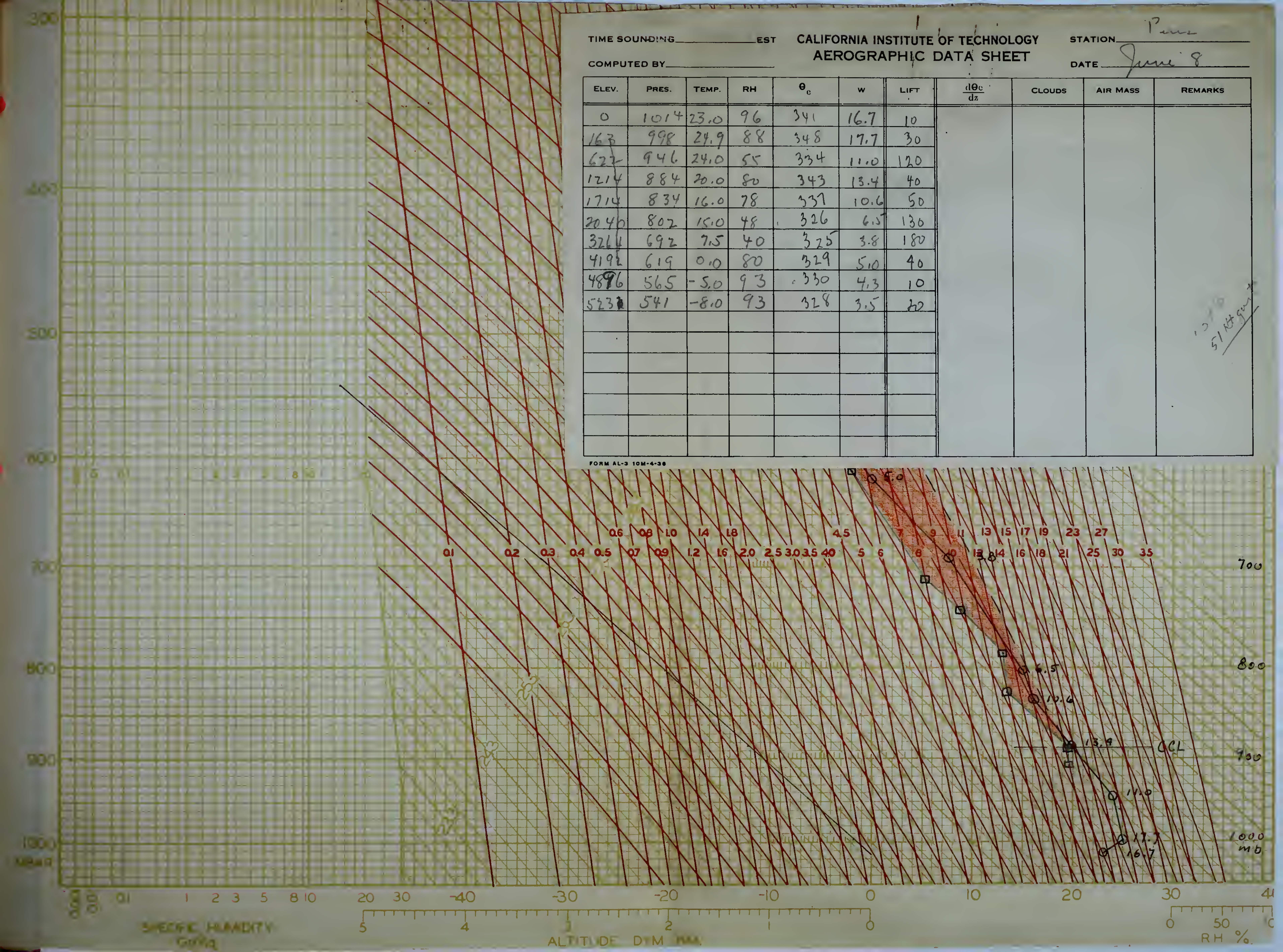
CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

STATION Pas

DATE June 8

ELEV.	PRES.	TEMP.	RH	θ_e	W	LIFT	$\frac{d\theta_e}{dz}$	CLOUDS	AIR MASS	REMARKS
0	1014	23.0	96	341	16.7	10				
163	998	24.9	88	348	17.7	30				
622	946	24.0	55	334	11.0	120				
1214	884	20.0	80	343	13.4	40				
1714	834	16.0	78	337	10.6	50				
2040	802	15.0	48	326	6.5	130				
3264	692	7.5	40	325	3.8	180				
4192	619	0.0	80	329	5.0	40				
4896	565	-5.0	93	330	4.3	10				
5232	541	-8.0	93	328	3.5	20				51 kt gust

FORM AL-3 10M-4-36



TIME SOUNDING ______ EST

COMPUTED BY ______

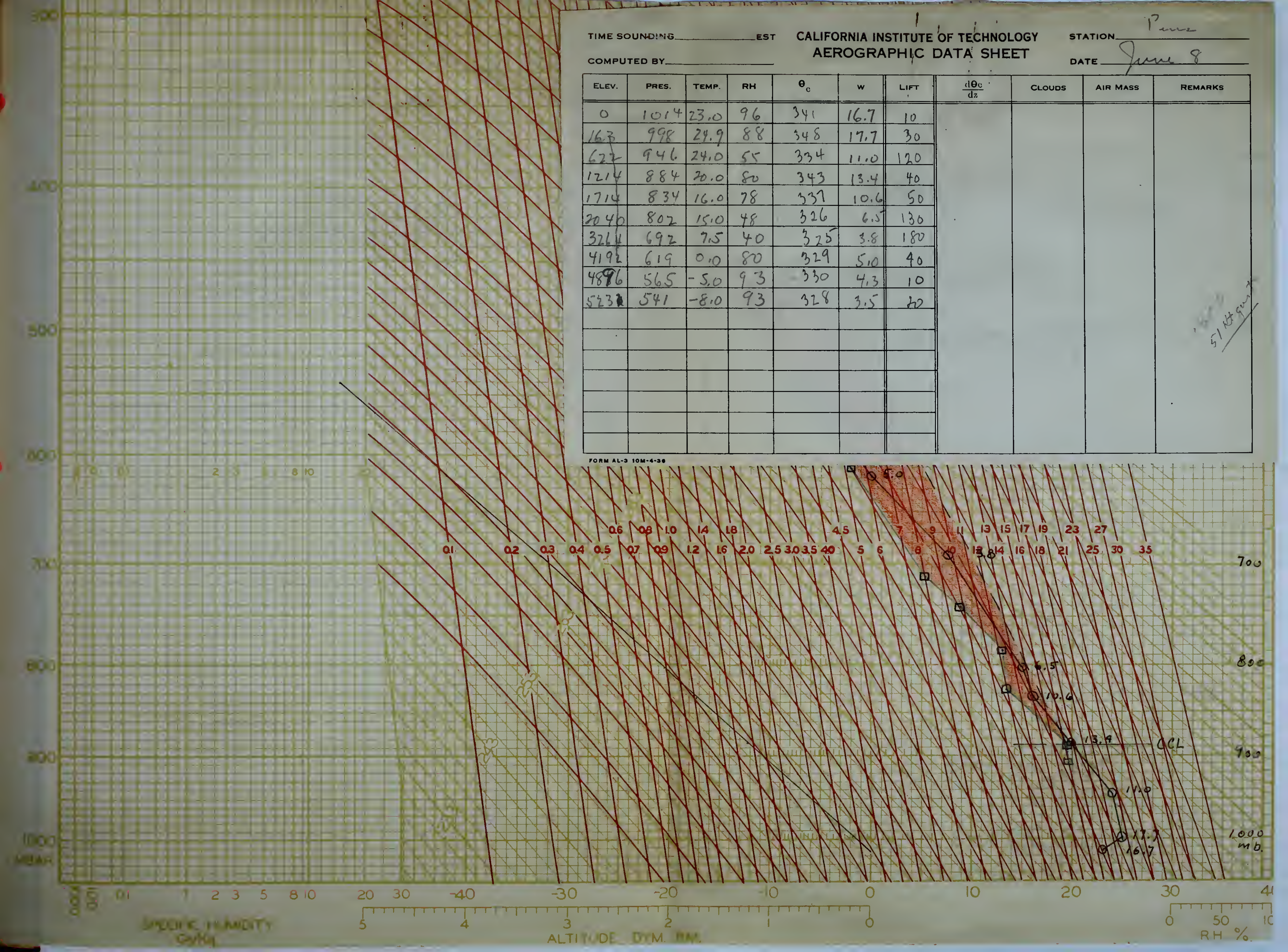
CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

STATION P[illegible]

DATE June 8

ELEV.	PRES.	TEMP.	RH	θ_c	w	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
0	1014	23.0	96	341	16.7	10				
163	998	24.9	88	348	17.7	30				
622	946	24.0	55	334	11.0	120				
1214	884	20.0	80	343	13.4	40				
1714	834	16.0	78	337	10.6	50				
2046	802	15.0	48	326	6.5	130				
3264	692	7.5	40	325	3.8	180				
4192	619	0.0	80	329	5.0	40				
4896	565	-5.0	93	330	4.3	10				
523[illegible]	541	-8.0	93	328	3.5	20				

FORM AL-3 10M-4-38



EXAMPLE # 3.

Lakehurst, New Jersey. 13 May, 1936.

This is type # 3, cold front thunderstorm situation.

The synoptic chart shows a cold front approaching the station from the west, distant about 180 miles on the morning of 13 May. The front is moving steadily eastward at about 20 miles per hour and should pass the station in the late afternoon. The air masses involved are Tg_2 at the station and the approaching mass, oPo.

From the aerograph curve it may be seen that the air mass now overlying the station is conditionally unstable for the greater part. Inspection shows that a maximum temperature of 35° C. is required for convections to reach the CCL, a temperature which far exceeds any to be expected at the station. The interest of the forecaster is then turned to the amount of lift required to release the potential instability of the air. In view of the approaching front a lift of 1000 meters is applied to each of the salient points of the original ascent curve. Curve # 2 is obtained by this operation.

Inspection of this curve shows that the original inversion, though reduced, has not been wiped out; but that the lower layers have become saturated to 725 millibars, 2820 meters. It is also to be noted that above 772 millibars, 2340 meters, the new curve lies to the left of the moist adiabatic through that point. With any further lifting a positive area will be developed from 772 millibars, 2340 meters, to the top of the curve. The ICL is contained within this

area at 622 millibars, 4100 meters.

The forecaster may be assured that with a lift of anything over 1000 meters, certainly to be obtained from the approaching front, there will be free convection extending from 772 millibars, 2340 meters, with continuous accelerations, to the ICL at 4100 meters and above that point for a distance which cannot be estimated. A thunderstorm, accompanied by rain, should be predicted for the station for the first forecast period.

A thunderstorm occurred over the station at 1500, unfortunately the type of precipitation was not reported. The cold front passed the station at 1730.

TIME SOUNDING .... EST

CALIFORNIA INSTITUTE OF TECHNOLOGY
AERODYNAMIC DATA SHEET

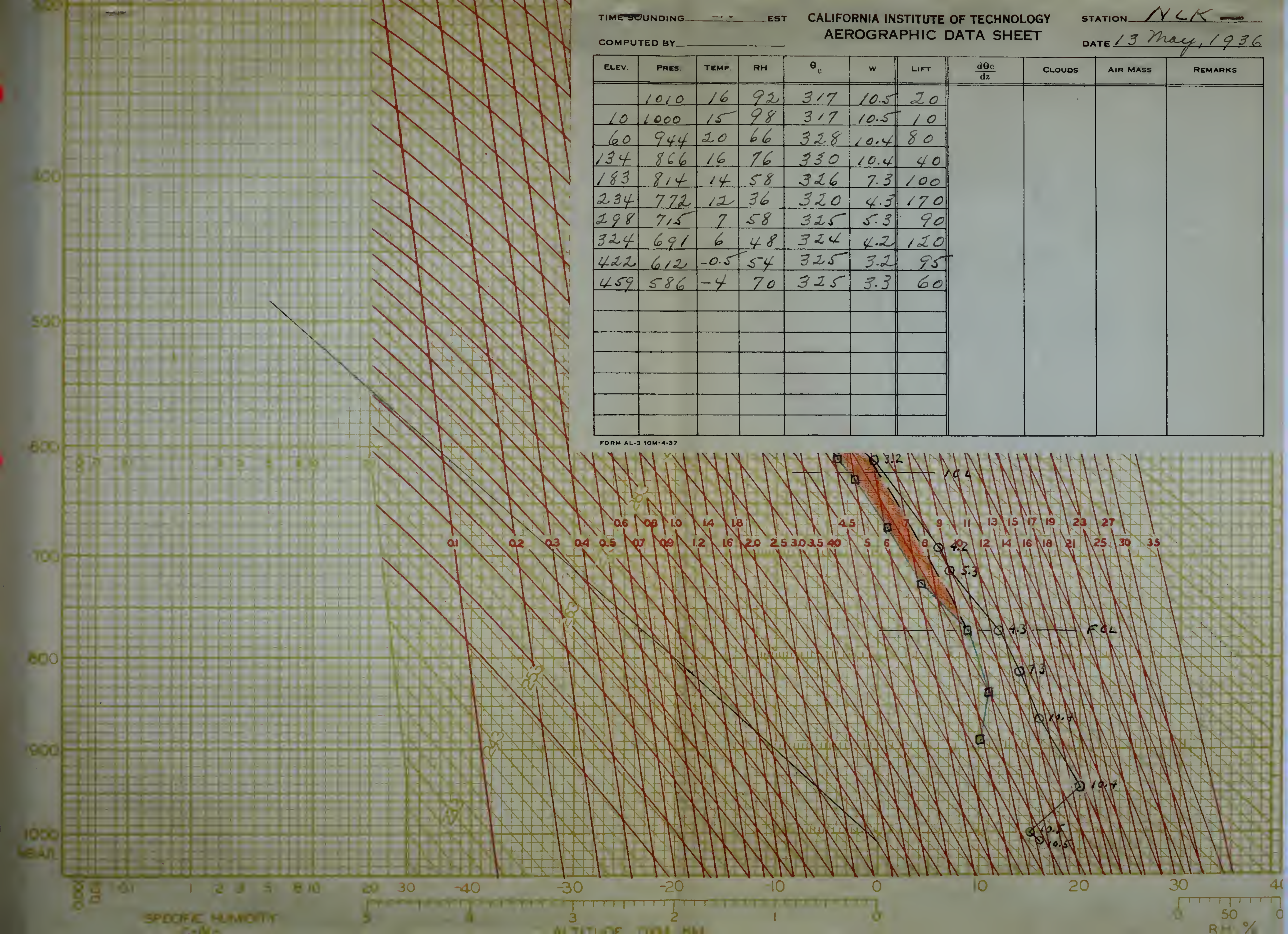
STATION NLK

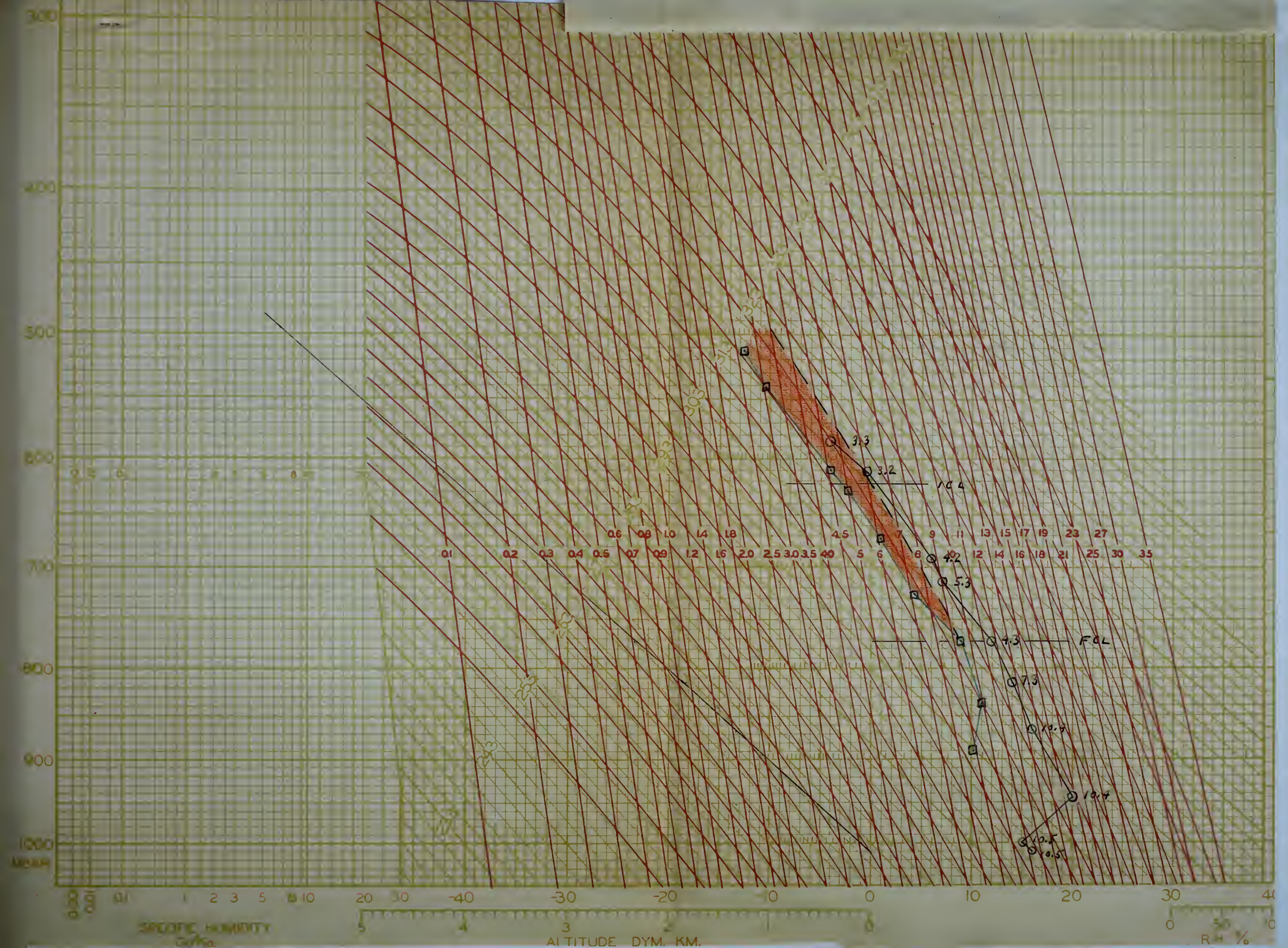
COMPUTED BY

DATE 13 May, 1936

ELEV.	PRES.	TEMP.	RH	θ_c	w	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1010	16	92	317	10.5	20				
10	1000	15	98	317	10.5	10				
60	944	20	66	328	10.4	80				
134	866	16	76	330	10.4	40				
183	814	14	58	326	7.3	100				
234	772	12	36	320	4.3	170				
298	715	7	58	325	5.3	90				
324	691	6	48	324	4.2	120				
422	612	-0.5	54	325	3.2	95				
459	586	-4	70	325	3.3	60				

FORM AL-3 10M-4-37





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MBAR
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-20
-10
0
10
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30
40
SPECIFIC HUMIDITY
ALTITUDE DYM. KM.
R.H. %
3.3
3.2
ICL
4.2
5.3
4.3
FCL
7.3
10.4
10.5

EXAMPLE # 4.

Anacostia, Virginia. 13 May, 1936

This is type # 3, cold front thunderstorm situation.

The synoptic chart shows a cold front approaching the station from the west, distant about 140 miles on the morning map. The front is moving east steadily at about 20 miles per hour and should pass the station during the afternoon. The air masses involved are Tg_2 and oPo.

From the aerograph curve, plotted on the adiabatic chart it may be seen that the air now overlying the station is conditionally unstable throughout the greater part. Inspection shows a maximum temperature of 33°2 C. required for free convection induced by surface heating, a temperature which exceeds the normal for the date at the station.

The amount of lift which will be required to release the potential instability of the air is now investigated. In view of the approaching front a lift of 1000 meters is applied to each of the salient points of the ascent curve. Curve # 2 is obtained from this operation.

Inspection of this curve shows that the original inversion, though reduced, has not been wiped out; but that the lower layers have become saturated to 625 millibars, 4120 meters. It is also to be noted that above 820 millibars, 1890 meters, the new curve is everywhere to the left of the moist adiabatic through that point. With any further lifting a positive area will be developed from 820 millibars, 1890 meters,

EXAMPLE # 4.

Anacostia, Virginia.   13 May, 1936

This is type # 3, cold front thunderstorm situation.

The synoptic chart shows a cold front approaching the station from the west, distant about 140 miles on the morning map. The front is moving east steadily at about 30 miles per hour and should pass the station during the afternoon. The air masses involved are TGg and NPw.

From the aerograph curve, plotted on the adiabatic chart it may be seen that the air now overlying the station is conditionally unstable throughout the greater part. Inspection shows a maximum temperature of 33°2 C. required for free convection induced by surface heating, a temperature which exceeds the normal for the date at the station.

The amount of lift which will be required to release the potential instability of the air is now investigated. In view of the approaching front a lift of 1000 meters is applied to each of the salient points of the ascent curve. Curve # 2 is obtained from this operation.

Inspection of this curve shows that the original inversion, though reduced, has not been wiped out; but that the lower layers have become saturated to 680 millibars, 4130 meters. It is also to be noted that above 820 millibars, 1800 meters, the new curve is everywhere to the left of the moist adiabatic through that point. With any further lifting a positive area will be developed from 820 millibars, 1800 meters,

to the top of the curve. The ICL is contained within this area at 600 millibars, 4480 meters.

The forecaster may be assured that with a lift of anything over 1000 meters, certainly to be obtained from the approaching cold front, he will have free convections extending from 820 millibars, 1890 meters, with continuous accelerations to the ICL, a distance of 2590 meters, and for a distance beyond that point which cannot be estimated. He should predict a thunderstorm, accompanied by moderate rain, for the station during the first forecast period.

A thunderstorm occurred over the station at 1430. Unfortunately the type and amount of precipitation was not reported. The cold front passed the station at about 1530.

TIME SOUNDING ______ EST

COMPUTED BY ______

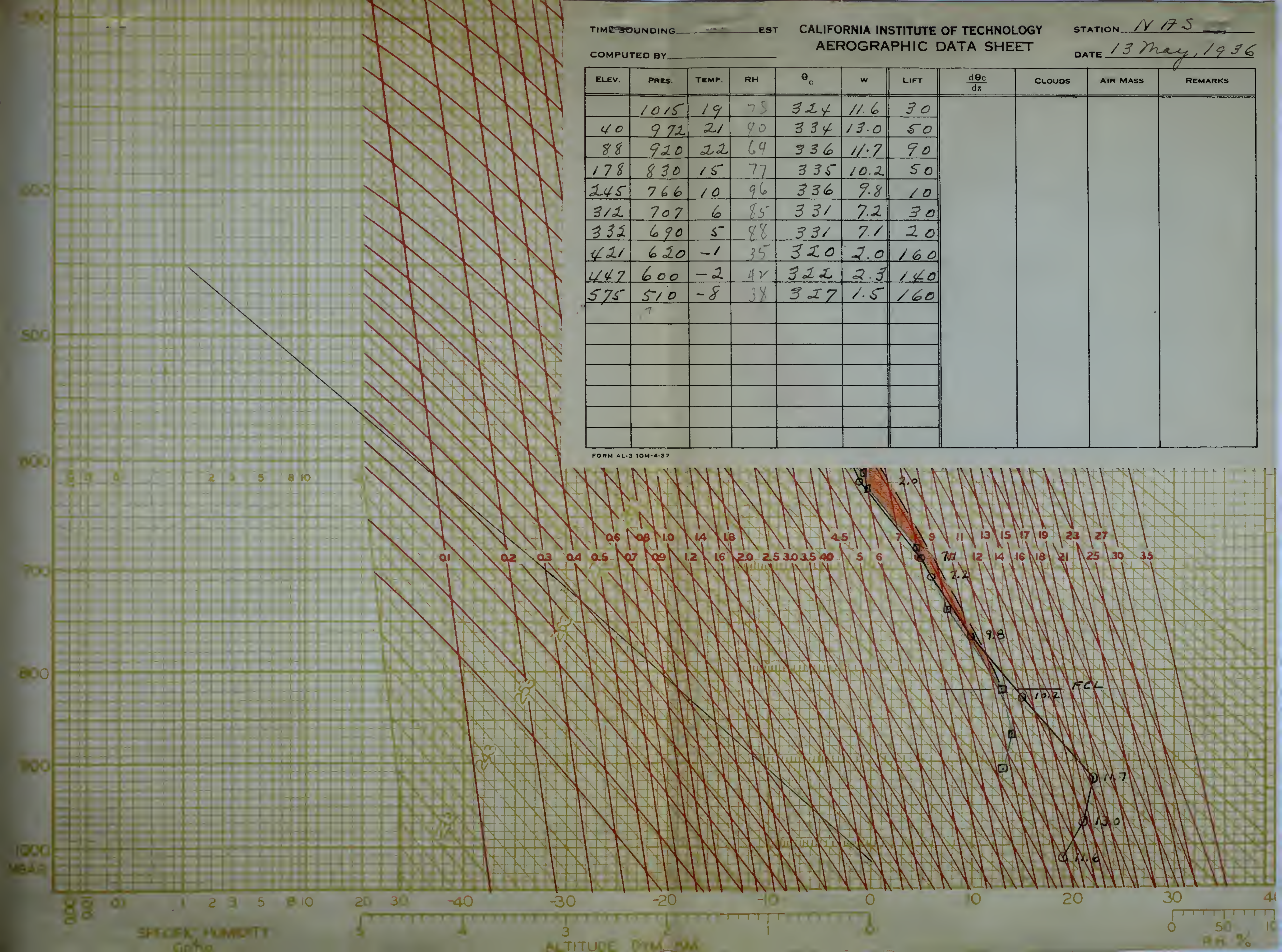
CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

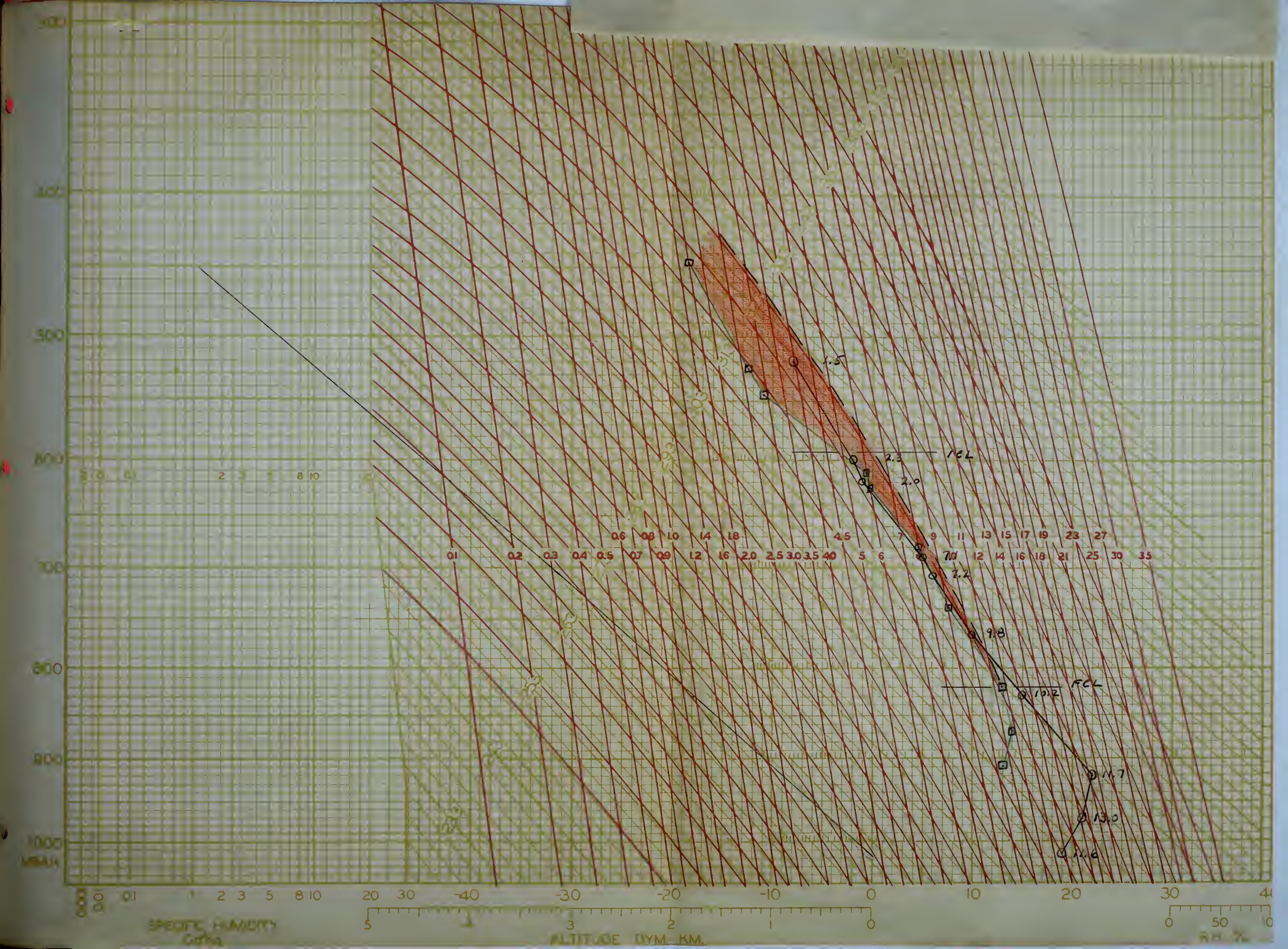
STATION *N A S*

DATE *13 May, 1936*

ELEV.	PRES.	TEMP.	RH	θ_c	W	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1015	19	75	324	11.6	30				
40	972	21	90	334	13.0	50				
88	920	22	64	336	11.7	90				
178	830	15	77	335	10.2	50				
245	766	10	96	336	9.8	10				
312	707	6	85	331	7.2	30				
332	690	5	88	331	7.1	20				
421	620	-1	35	320	2.0	160				
447	600	-2	42	322	2.3	140				
575	510	-8	38	327	1.5	160				

FORM AL-3 10M-4-37





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MBAR
LCL
FCL
1.5
2.3
2.0
2.2
9.8
10.2
11.7
13.0
14.6
-40
-30
-20
-10
0
10
20
30
SPECIFIC HUMIDITY
ALTITUDE DYM. KM.
R.H. %

EXAMPLE # 5.

Northeast Arkansas. 23 April, 1937.

This is type # 5, cold front thunderstorm situation.

The synoptic chart for 22 April shows a rather complicated cold front running SW-NE through the panhandle of Texas and moving to the southeast at approximately 22 miles per hour. A flow of Tg is being brought north, induced by the low pressure centered in Iowa. The air masses involved are Tg and $_3Pp_5$ in the warm sector, $_1Pp_3$ and Pc_3 behind the cold front.

This example passes from station forecasting to the wider range of district, for the investigation of the weather phenomena associated with such a rapidly moving and complicated frontal system must be more general.

In this case it is seen from the Shreveport sounding for 22 April that Tg air has reached there, at least in the surface levels. Judging from the cloud drift the upper winds are generally south, veering to southwest. The velocities can only be estimated, but from such pilot balloon runs as are available it seems that they approach 35 miles per hour.

Plotting the Shreveport sounding on an adiabatic chart it is seen that, with the present structure, the air over that station now will not be susceptible to convections due to surface heating. Going to the lifting process, remembering that the swiftly moving front to the northwest will provide a ready agency for lifting, the salient points are each lifted 1000 meters. From this operation curve # 2 is obtained,

EXAMPLE # 5.

Northeast Arkansas. 23 April, 1937.

This is type # 5, cold front thunderstorm situation.

The synoptic chart for 22 April shows a rather complicated cold front running SW-NE through the panhandle of Texas and moving to the southeast at approximately 25 miles per hour. A flow of Tg is being brought north, induced by the low pressure centered in Iowa. The air masses involved are Tg and gPg in the warm sector; $_1Pg$ and Pc_3 behind the cold front.

This example passes from station forecasting to the wider range of district, for the investigation of the weather phenomena associated with such a rapidly moving and complicated frontal system must be more general.

In this case it is seen from the Shreveport sounding for 21 April that Tg air has reached there, at least in the surface levels. Judging from the cloud drift the upper winds are generally south, veering to southwest. The velocities can only be estimated, but from such pilot balloon runs as are available it seems that they approach 30 miles per hour.

Plotting the Shreveport sounding on an adiabatic chart it is seen that, with the present structure, the air over that station now will not be susceptible to convections due to surface heating. Going to the lifting process, remembering that the swiftly moving front to the northwest will provide a ready agency for lifting, the salient points are each lifted 1000 meters. From this operation curve 4 ? is obtained,

with saturation extending up to 729 millibars, 2800 meters. With further lifting that air now at 839 millibars, 1610 meters, will ascend the moist adiabatic through that point. It will provide a positive area from there to 715 millibars, 3000 meters, where it will run into a resistant area, the remains of the strong inversion from the original curve. This resistant area extends to 552 millibars, 5380 meters, and it is believed that it will be strong enough to block convections at that point. It can be seen that either further lifting must be anticipated or that the probable effects of convergence be applied to see what will result.

Assuming 20% convergence of mass due to the rapidly moving front, and remembering that convergence is applied to the pressure difference between each salient point and the surface point, presuming mass roughly proportional to the pressure, curve # 3 is obtained from curve # 2. It is seen that this last manuever has reduced the inversion of the original curve to a point where its maximum point lies just on the moist adiabatic which passes through 830 millibars, 1700 meters. The resistant area has been completely destroyed and there could be free convection from 1700 meters to the top of the curve, with accelerations being continuous but a minimum at 600 millibars, 4400 meters, increasing thereafter.

However, realizing that there is no quantitative means of measuring convergence and that its use is merely a guess as to the amount to expect, the original ascent curve is again operated on, this time using 1500 meters lift. From this

operation curve # 4 is obtained. From this curve it is seen that any further lifting will result in the formation of a positive area extending from 792 millibars, 2100 meters, to 618 millibars, 4150 meters, there a slight resistant area is encountered, 28 millibars, 400 meters, thick. This would not prove an obstacle and convection would pass through that layer above which lies another positive area increasing in size to the top of the curve. The ICL lies at 620 millibars, 4140 meters. Attention is invited to the similarity of curves # 3 and # 4, indicating that in this case a convergence of 20% is practically equivalent to a lift of 500 meters.

The air, now over Shreveport, if lifted 1500 meters, or 1000 meters with an assumed convergence of 20%, will be in a state where any further lifting will result in the realization of the potential instability contained therein. Thunderstorms should occur, accompanied by hail and rain.

The next question to consider is, where may it be expected that this lift will be realized? Considering the flow of T_G to be about 35 miles per hour from the southwest, veering to west with northerly distance gained, and the computed or extrapolated movement of the front to be about 22 miles per hour in a southeasterly direction it appears that the southern part of Illinois and a line extending from there southerly through western Louisiana should have cold front thunderstorms of considerable intensity starting early on 23 April.

Thunderstorms of considerable intensity, accompanied by destructive hail in northeast Arkansas, and extended over a long line running from there to the south-southwest, started during the night of 22-23 April and continued along the cold front during the 23rd. Tornado-like winds occurred along the front during the night.

TIME SOUNDING 0400 EST

COMPUTED BY

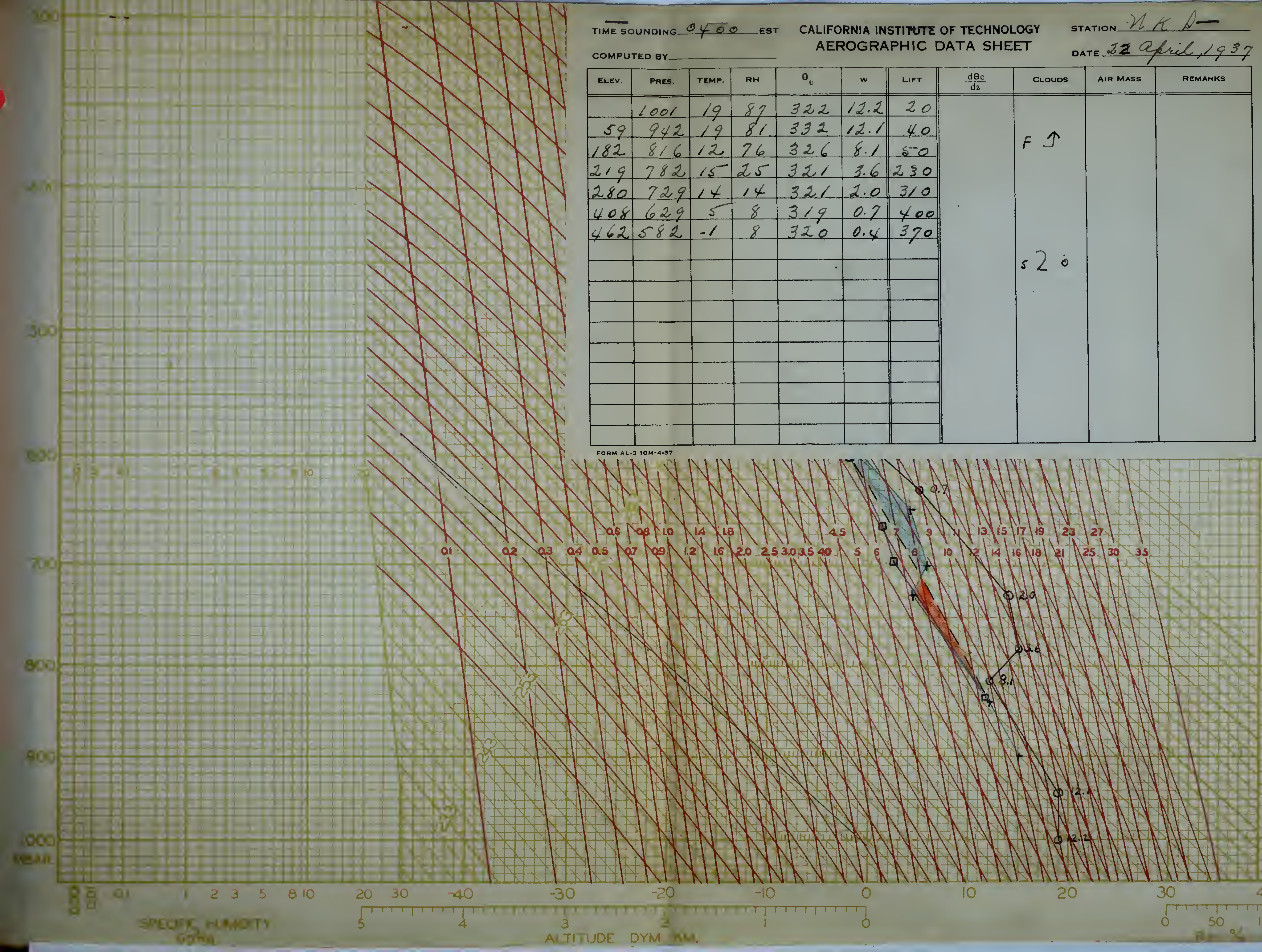
CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

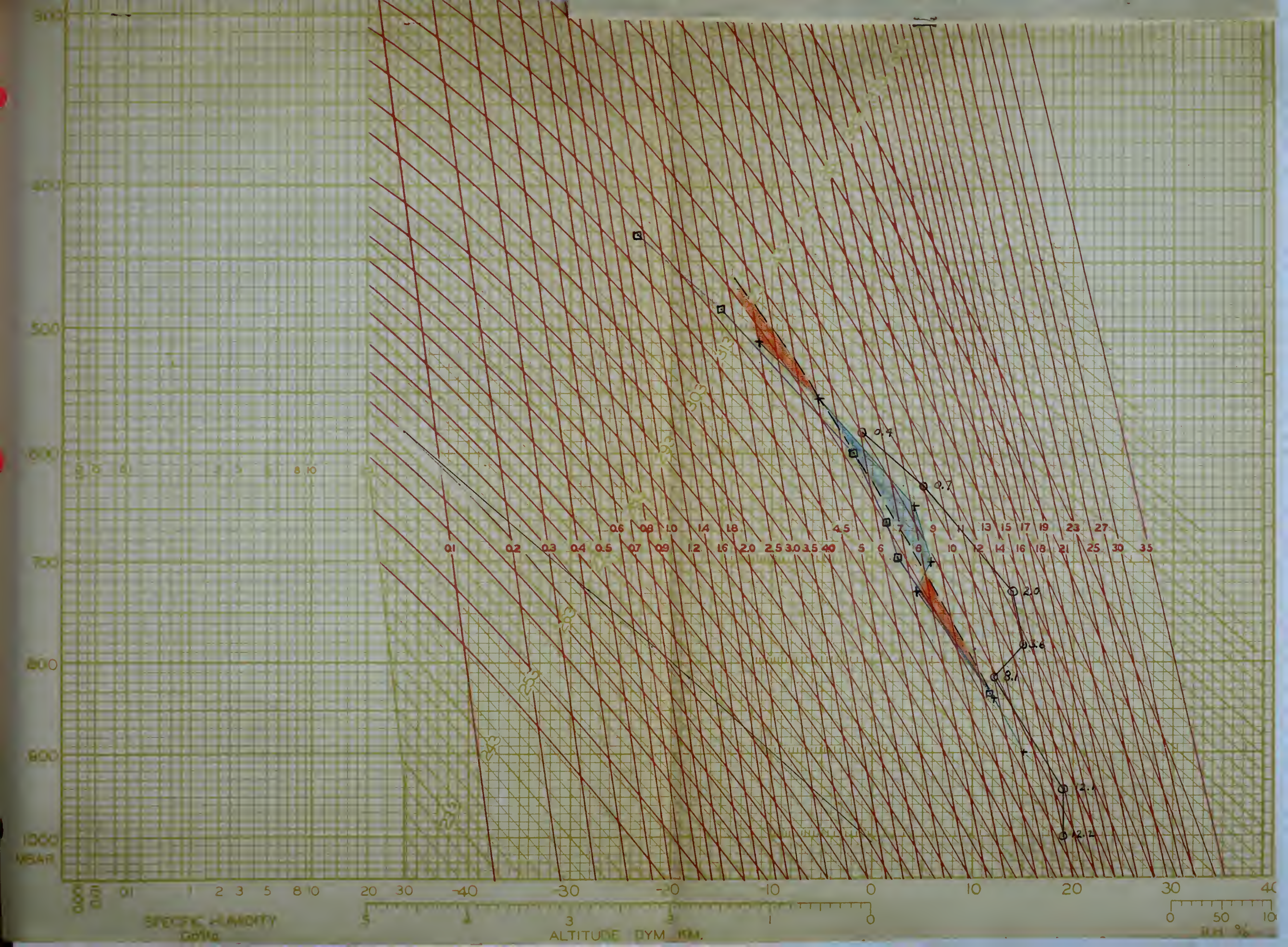
STATION N K D

DATE 22 April, 1937

ELEV.	PRES.	TEMP.	RH	θ_c	W	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1001	19	87	322	12.2	20				
59	942	19	81	332	12.1	40		F ↑		
182	816	12	76	326	8.1	50				
219	782	15	25	321	3.6	230				
280	729	14	14	321	2.0	310				
408	629	5	8	319	0.7	400				
462	582	-1	8	320	0.4	370		s 2 o		

FORM AL-3 10M-4-37





300
400
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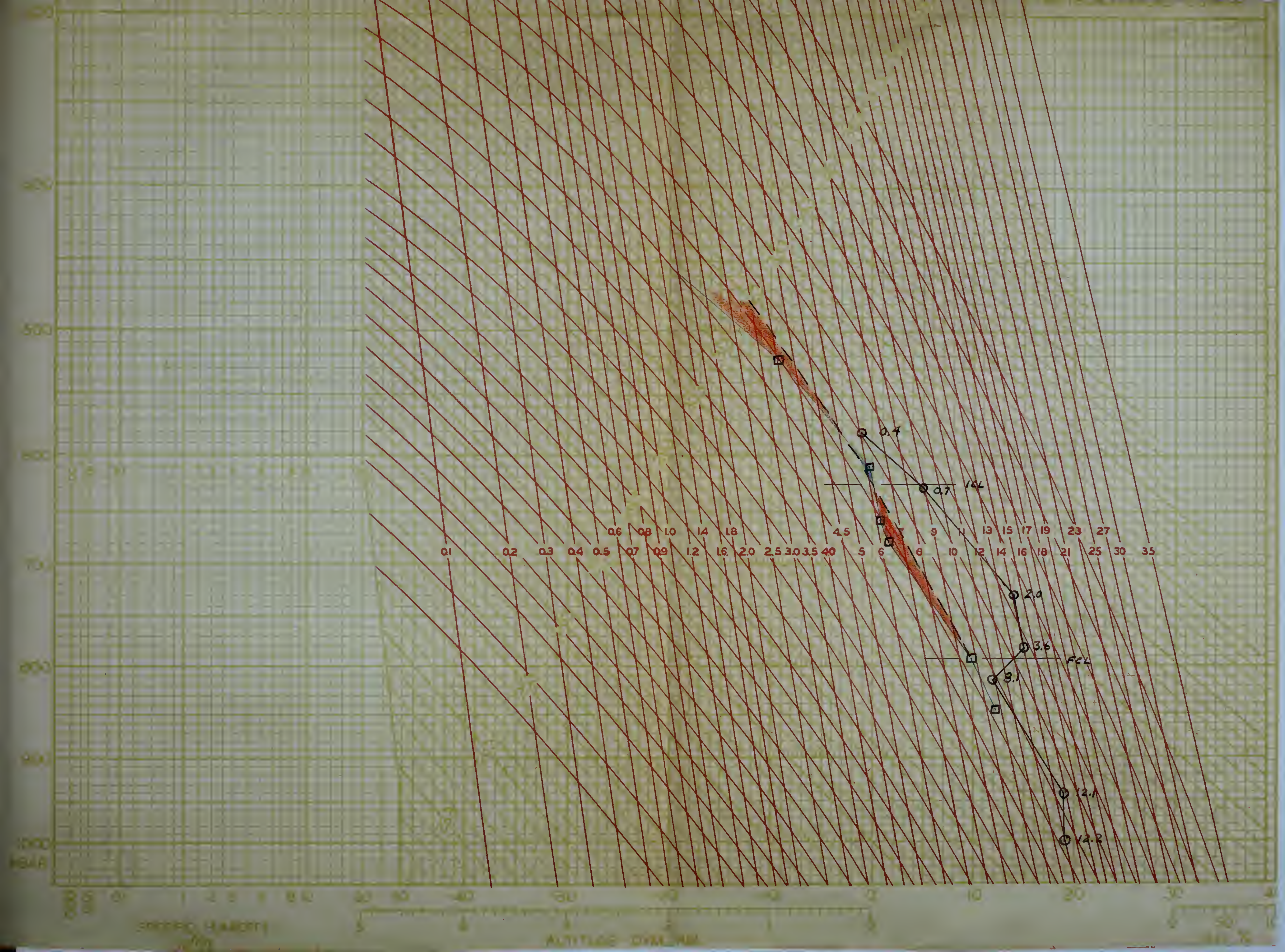
1000
MBAR
SPECIFIC HUMIDITY
G/KG
ALTITUDE DYM. KM.
R.H. %
0.4
0.7
2.0
3.6
3.1
12.1
12.2



0.6 0.8 1.0 1.4 1.8 4.5 7 9 11 13 15 17 19 23 27
0.1 0.2 0.3 0.4 0.5 0.7 0.9 1.2 1.6 2.0 2.5 3.0 3.5 4.0 5 6 8 10 12 14 16 18 21 25 30 35
0.4
0.7
ICL
2.0
3.6
FCL
8.1
12.1
12.2

EXAMPLE # 6.

Dallas, Texas. 29 April, 1937.

This is type # 5, cold front thunderstorm situation.

The synoptic chart shows a cold front 130 miles to the west of Dallas on the morning of 28 April. It is moving to the east and decellerating. The air masses involved are oPco approaching Tg in the warm sector with $_4Pp_2$ and RPc_6 the cold masses.

In view of the synoptic situation the air mass structure which would interest the Dallas forecaster is not that overlying his station at the time of the morning map but rather that which will be over Dallas when the cold front is in close enough proximity to his station to be an active lifting agent. Judging from the upper air soundings at the pilot balloon run the air mass which is now over San Antonio, and whose aerograph sounding is available, is the air most similar to that which should be over Dallas at a time when frontal activity may be expected. In the absence of any better data the forecaster must use this sounding to estimate the structure of the air.

The San Antonio aerograph sounding was taken at 1000 C.S. 28 April. Plotted on the adiabatic chart it is seen that this air with its strong inversion will not be susceptible to convections due to surface heating. Considering the possibility of lift, since a front is approaching which will serve as a ready lifting agent, it is seen that a lift of approximately 2000 meters will be required to remove the inversion. The

salient points are each lifted 2000 meters and curve # 2 is obtained. It can be seen that the first three points are now saturated and the inversion is almost removed. It is also clear that further lifting will result in the development of a positive area extending from 728 millibars, 2820 meters, to the top of the curve. The ICL is at 574 millibars, 4780 meters. If two kilometers of lift can be provided the air which is now over San Antonio will be ready to release its potential instability, for there will be continuously increasing accelerations on a particle from 2820 meters to the ICL, and for a distance beyond that point which cannot be estimated.

The next question to be considered is whether this condition may be realized at Dallas. The computed or extrapolated movement of the front indicates that it should pass Dallas at about 0700 C.S. 29 April. An estimate of the trajectory of the air at present over San Antonio indicates that it should be overlying Dallas after midnight. In view of the movement of the front a thunderstorm, accompanied by rain and hail, should be predicted for Dallas, to occur during the early morning of 29 April.

A thunderstorm occurred over Dallas from 0500 to 0600 C.S. time. It was accompanied by hail and moderate rain.

TIME SOUNDING 1100 EST

COMPUTED BY

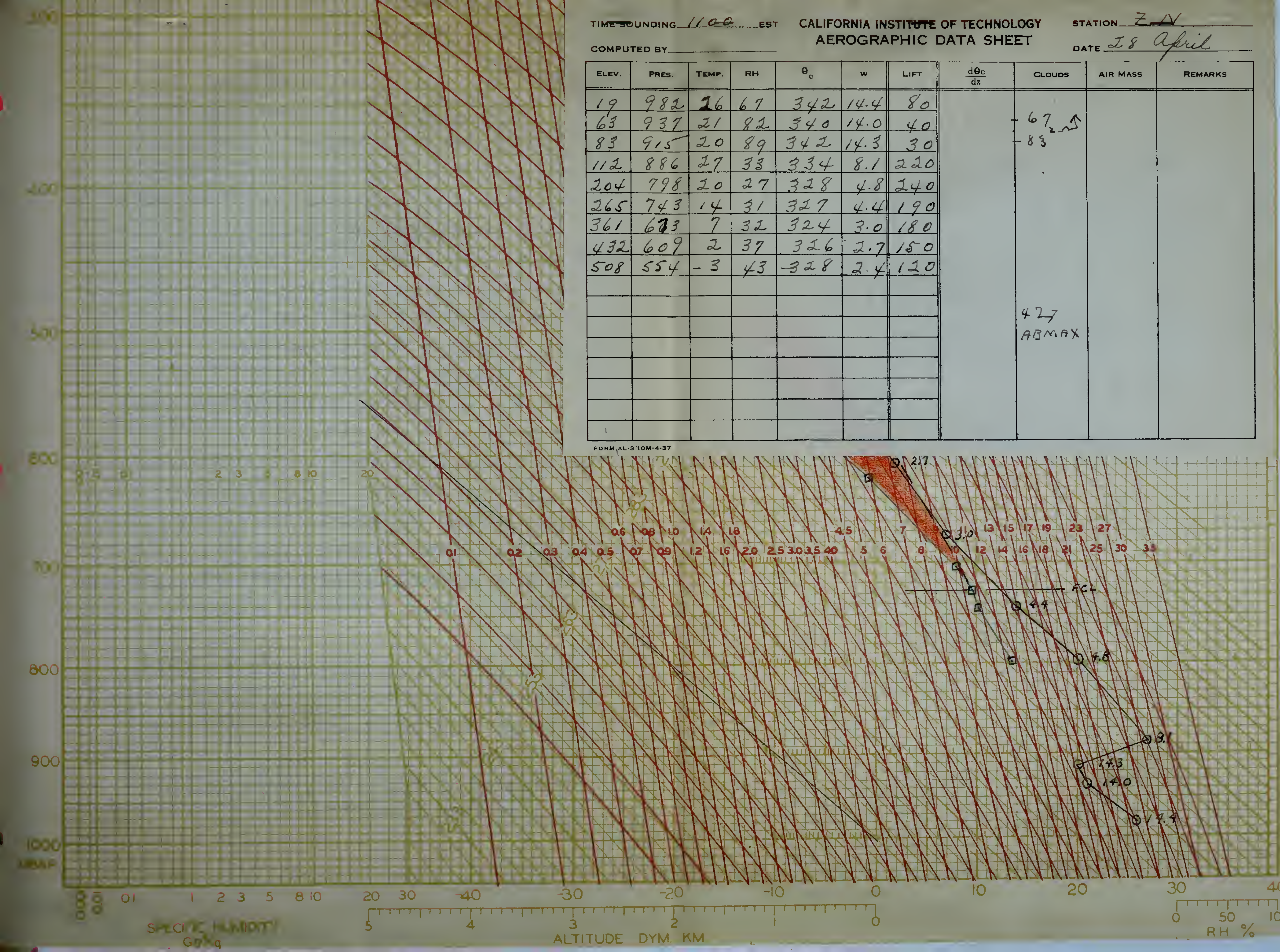
CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

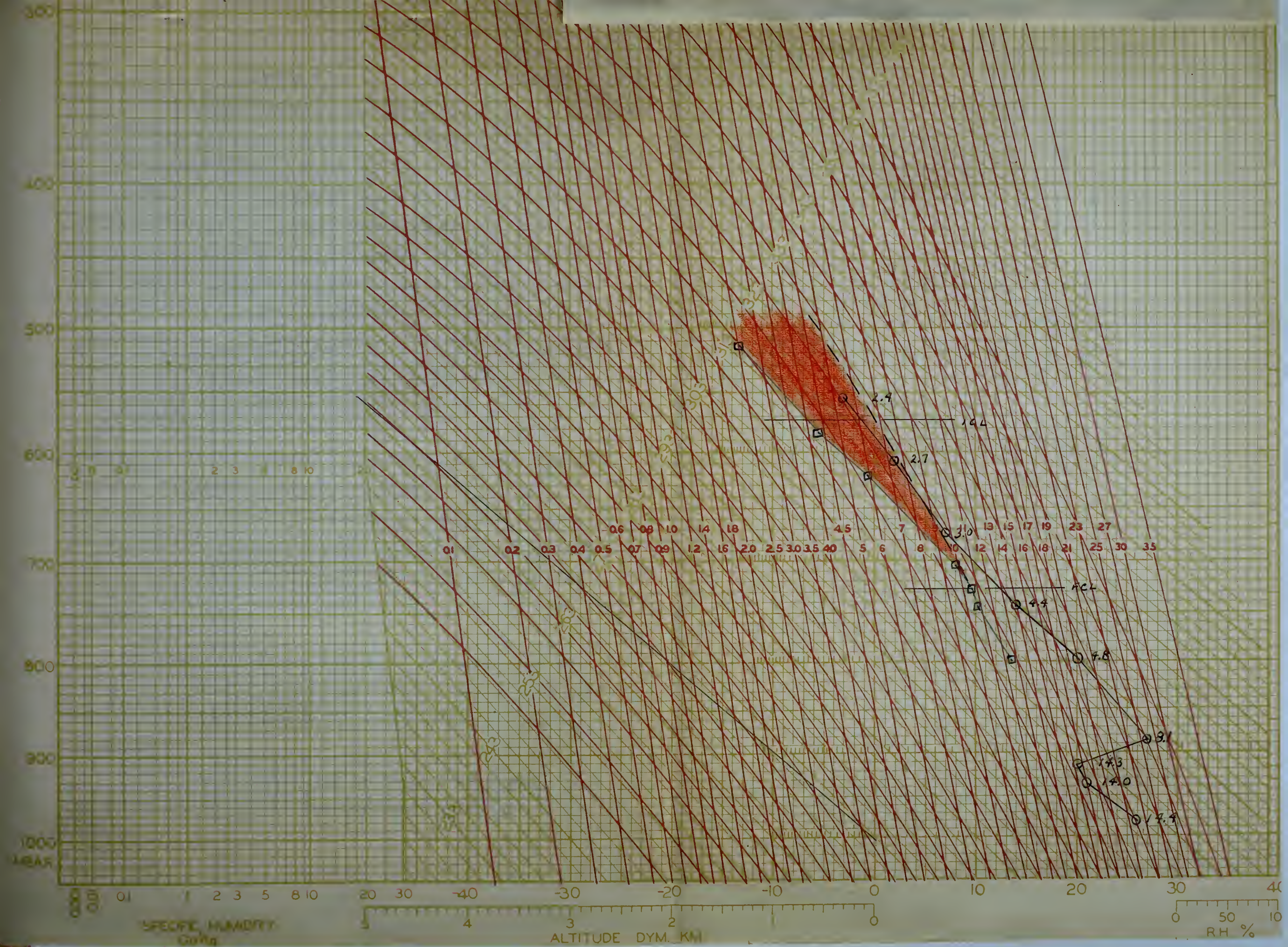
STATION Z-IV

DATE 28 April

ELEV.	PRES.	TEMP.	RH	θ_c	W	LIFT	$\frac{d\theta c}{dz}$	CLOUDS	AIR MASS	REMARKS
19	982	26	67	342	14.4	80				
63	937	21	82	340	14.0	40		67		
83	915	20	89	342	14.3	30		83		
112	886	27	33	334	8.1	220				
204	798	20	27	328	4.8	240				
265	743	14	31	327	4.4	190				
361	673	7	32	324	3.0	180				
432	609	2	37	326	2.7	150				
508	554	-3	43	328	2.4	120				
								427 ABMAX		

FORM AL-3 10M-4-37





300
400
500
600
700
800
900
1000
MBAR
-40
-30
-20
-10
0
10
20
30
40
SPECIFIC HUMIDITY
G/kg
ALTITUDE DYM. KM
RH %
ACL
2.4
2.7
3.0
4.4
4.8
9.1
14.3
14.0
17.4

EXAMPLE # 7.

Murfreesboro, Tennesse. 30 April, 1937.

This is type # 5, cold front thunderstorm situation.

The synoptic chart for the morning of 29 April shows a warm front just to the north of Murfreesboro. It has been moving northward very slowly, accompanied by warm front thunderstorm conditions. The air masses involved are Tg_1 and R_1Pco. The afternoon map shows a large isallobaric high formed over the East Coast from New York to Virginia. The indications are pointing to a southerly movement of the high pressure center now situated over Quebec Province. In case this movement materializes the warm front, now to the north of Murfreesboro, will regress and turn into a cold front. However, the over-running of the Tg_1 will continue, with its vertical component of motion accelerated by the southward movement of the high and the squeezing produced by the convergence of the fronts to the west and north of Murfreesboro. This should produce violent thunderstorm activity, and is a situation analagous to that in which the U.S.S. Akron was lost in April, 1933.

Following the teletype reports, if available, the Murfreesboro observer could see that the front to the north was regressing and would recross his station during the morning of 30 April.

In this case, judging from the pilot balloon runs, the trajectory of the air now over Shreveport on 29 April will

cause it to be approximately the air which will be at the front as it returns to the vicinity of Murfreesboro. Plotting the Shreveport aerograph sounding on the adiabatic chart it is obvious that no anticipated surface temperature will produce convections to the condensation level. However, it is seen that a lift of 1500 meters will be sufficeant to release the potential instability of the air. Replotting each of the salient points of the original curve with a lift of 1500 meters, it is seen that the first four points are saturated and that further lifting will allow a particle from the second point, 800 millibars, 2000 meters, to rise along the moist adiabatic through that point. Following along this moist adiabatic it is seen that everywhere the particle will be to the right of curve # 2, a positive area will extend from 800 millibars, 2000 meters, to the top of the curve. The ICL lies within this area at 572 millibars, 4200 meters. A particle which can be lifted through 800 millibars will be increasingly accelerated to the ICL and for a distance beyond that point which cannot be estimated.

In view of the synoptic situation the forecaster should anticipate severe thunderstorm conditions to occur over Murfreesboro during the morning of 30 April.

Severe thunderstorms, accompanied by heavy hail and rain, occurred at Murfreesboro and throughout the district around Tennesse and Missouri during the early morning of 30 April.

TIME SOUNDING 0400 EST

COMPUTED BY

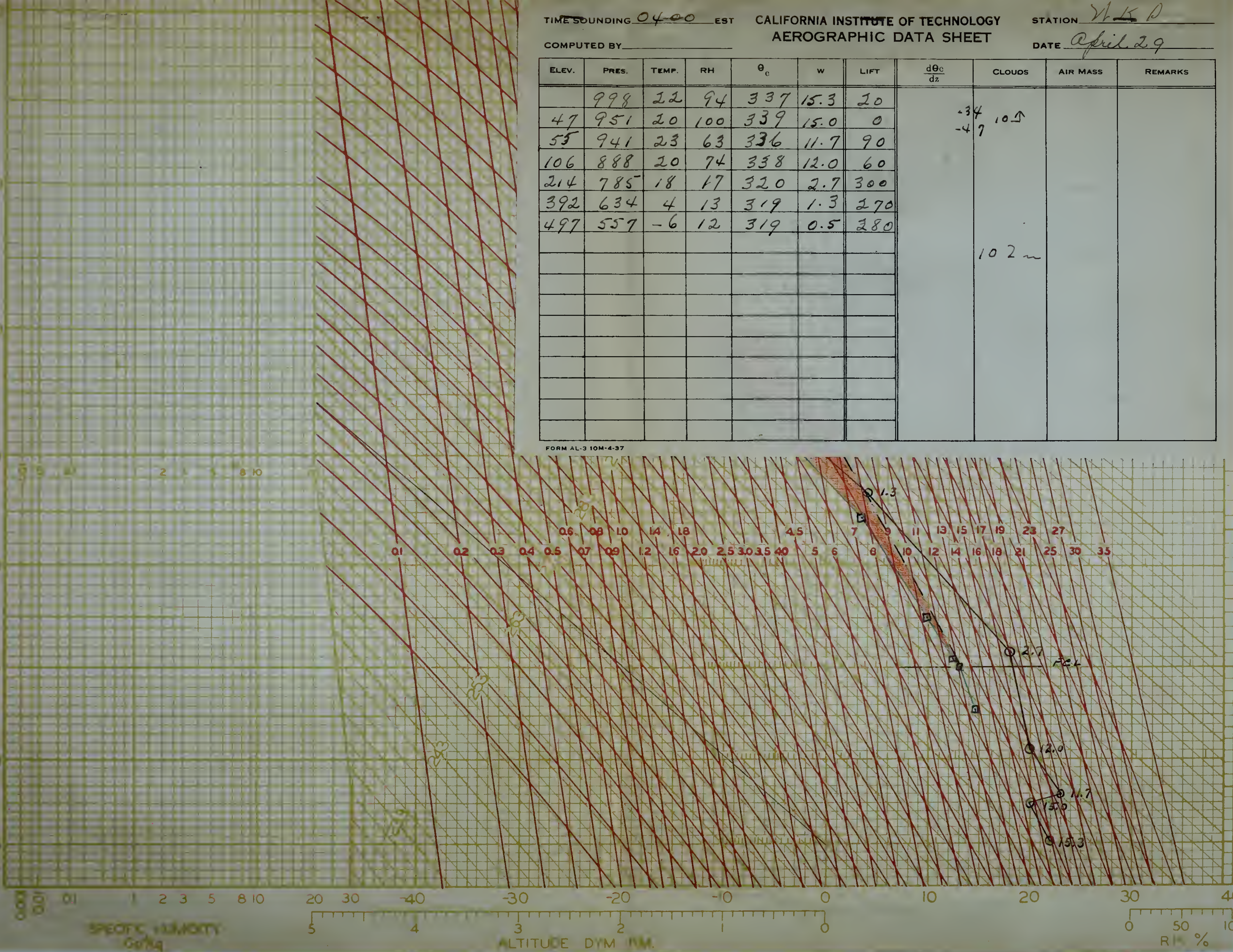
CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

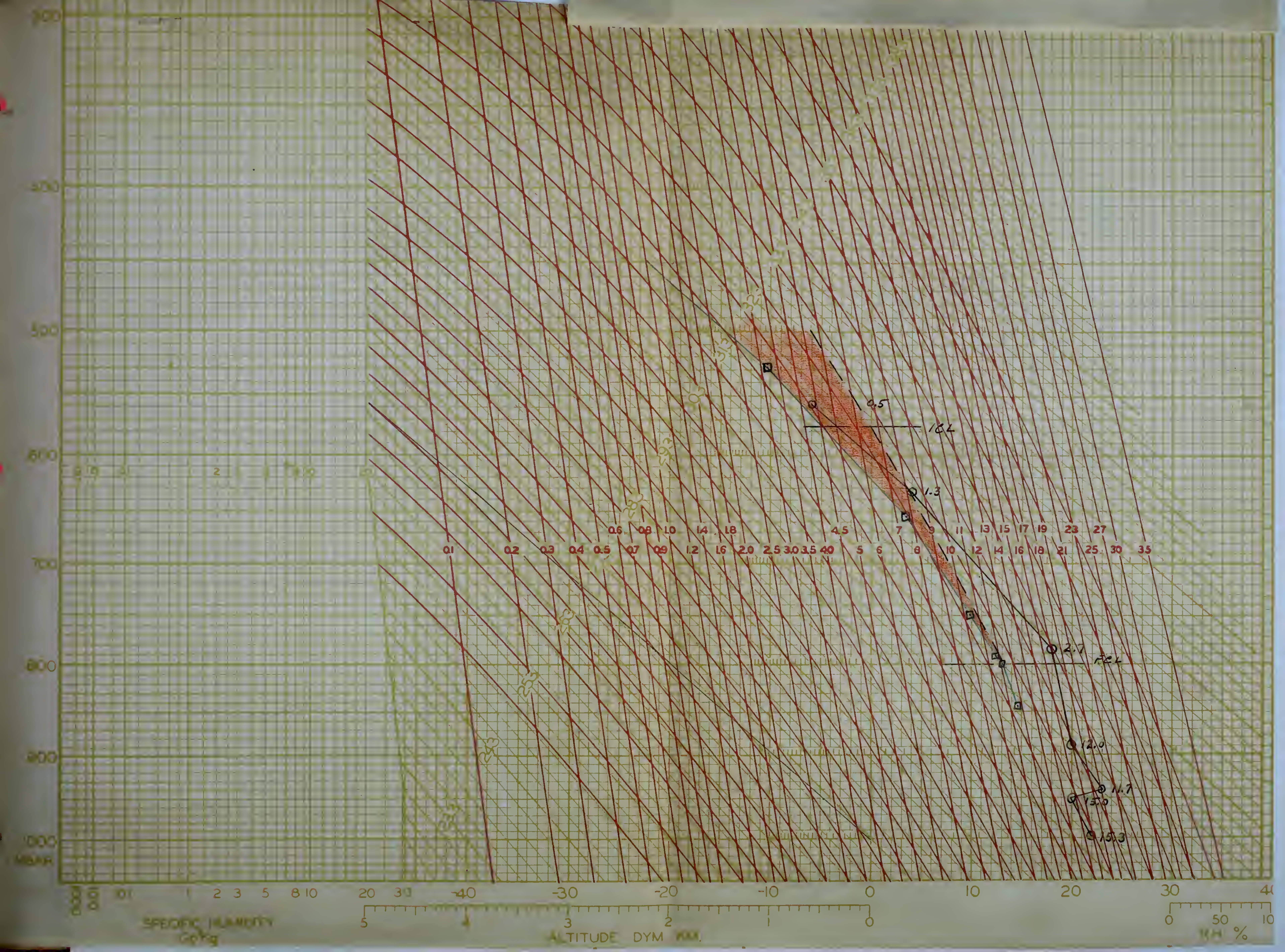
STATION NKP

DATE April 29

ELEV.	PRES.	TEMP.	RH	θ_c	W	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	998	22	94	337	15.3	20				
47	951	20	100	339	15.0	0	-34	10⇑		
55	941	23	63	336	11.7	90	-47			
106	888	20	74	338	12.0	60				
214	785	18	17	320	2.7	300				
392	634	4	13	319	1.3	270				
497	557	-6	12	319	0.5	280				
								10 2 ~		

FORM AL-3 10M-4-37





MBAR
SPECIFIC HUMIDITY G/KG
ALTITUDE DYM KM
RH %
0.5
1.3
2.7
12.0
11.7
15.0
15.3
ICL
FCL

EXAMPLE # 8.

Coco Solo, C.Z. 15 November, 1936.

This is type # 5, cold front thunderstorm situation.

This example of a cold front thunderstorm situation is offered for the unusual values of humidity found extending to the top of the aerograph curve, and for the fact that although the positive area is not nearly as large as other examples presented, it resulted in the most severe thunderstorm that occurred over this station since records have been kept.

Consideration of the synoptic chart shows a cold front approaching the station from the north. Naturally the front is decellerating, but by extrapolating its past movement it should pass the station during the afternoon. The air masses involved are Em at the station and the approaching mass, Pco.

From the aerograph curve, plotted on the adiabatic chart, it may be seen that the air mass now overlying the station is conditionally unstable from 964 millibars, 390 meters, to 644 millibars, 3820 meters.

It can readily be seen that no expected surface temperature will be high enough to develop free convections. So the forecasters attention is turned to the amount of lift required for free convection. If a lift of 500 meters is applied to the salient points of the original curve it is seen that the air will be saturated from the surface layer to 790 millibars, 2100 meters, and that any further lifting will cause the lower layers to rise along the moist adiabatic where they will be everywhere warmer than their surroundings. If the ascent

curve of a particle leaving the saturated layer is plotted it will show a positive area extending to the top of the ascent curve.

If a lift of 1000 meters is assumed, and the lifting procedure carried out, it is found that there is practically no increase in the positive area; this result could have been foreseen if it had been noted that the whole curve is practically in neutral equilibrium for the saturated condition, since the total change of the equivalent potential temperature over the sounding is but seven degrees.

Considering the adiabatic plot it is seen that the ICL is within the positive area at 542 millibars, 5280 meters. There will be continuous acceleration on a particle from 792 millibars, 2100 meters, to the ICL and for an undetermined distance beyond that point.

It is believed that a thunderstorm would be predicted by most forecasters in this situation. However, it is not believed that many would have anticipated such a violent thunderstorm as occurred, undoubtedly due to the large quantity of water vapor present throughout the air mass and to the possibility of a sharp falling off in water vapor at levels above the sounding.

A most violent thunderstorm, accompanied by 3.15" of rain, occurred over the station at 1710.

TIME SOUNDING 0700 EST

CALIFORNIA INSTITUTE OF TECHNOLOGY

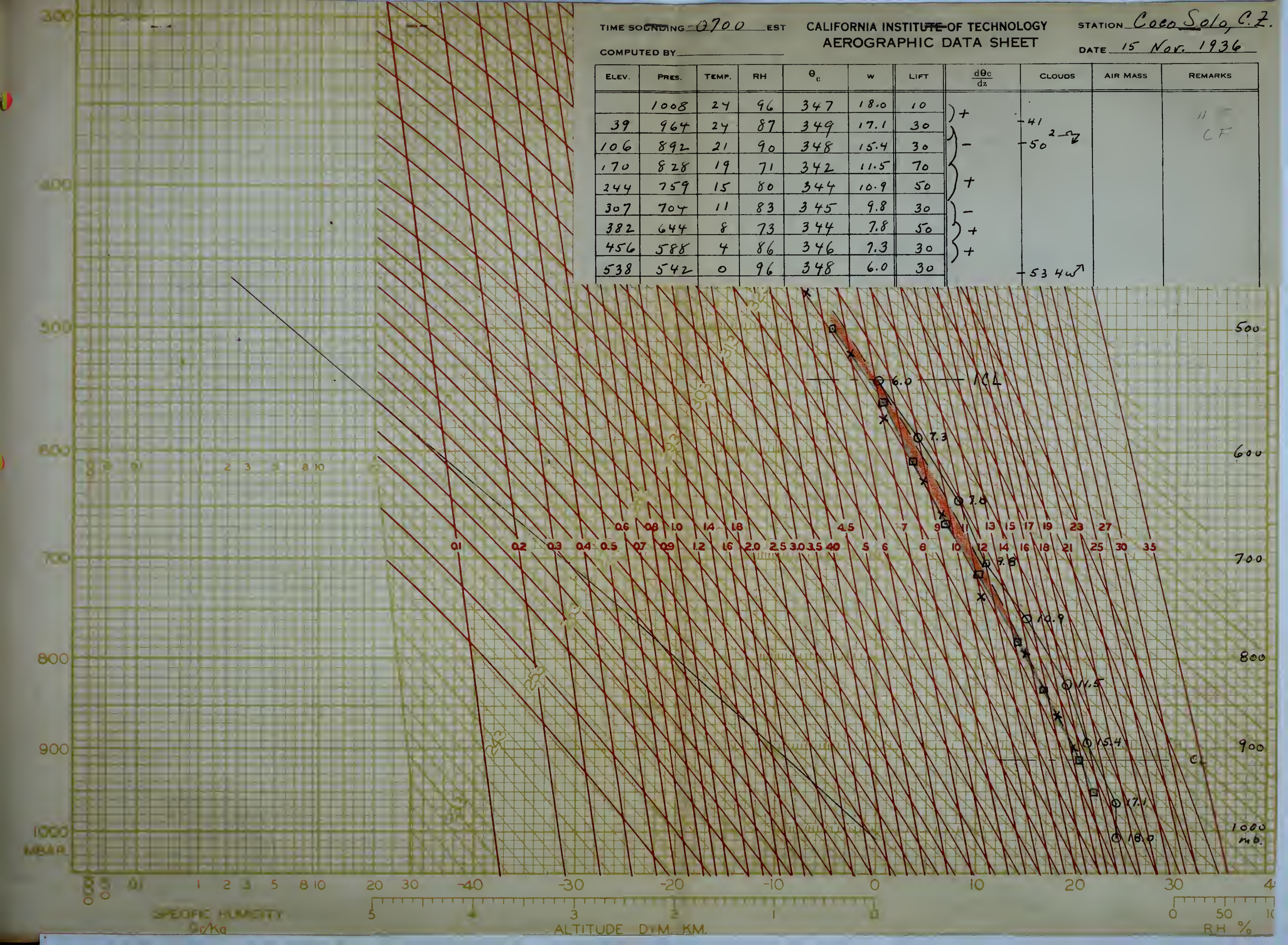
AEROGRAPHIC DATA SHEET

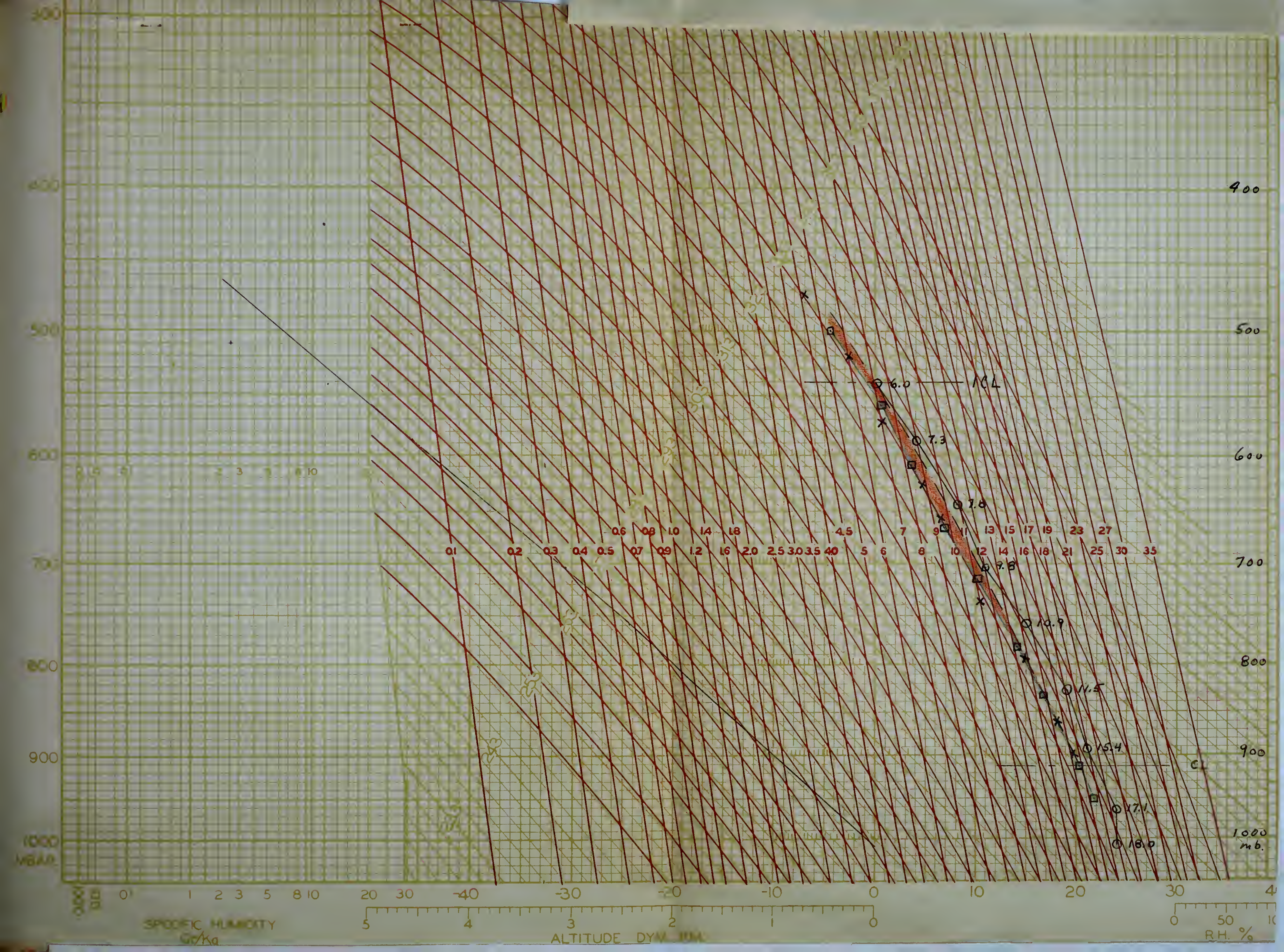
STATION Coco Solo, C.Z.

COMPUTED BY

DATE 15 Nov. 1936

ELEV.	PRES.	TEMP.	RH	θ_c	w	LIFT	$\frac{d\theta c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1008	24	96	347	18.0	10	+			H
39	964	24	87	349	17.1	30		41		CF
106	892	21	90	348	15.4	30	−	50 2		
170	828	19	71	342	11.5	70				
244	759	15	80	344	10.9	50	+			
307	704	11	83	345	9.8	30	−			
382	644	8	73	344	7.8	50	+			
456	588	4	86	346	7.3	30	+			
538	542	0	96	348	6.0	30		53 4w		





400
500
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MBAR
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ICL
7.3
7.8
9.8
10.9
11.5
15.4
17.1
18.0
CL
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500
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700
800
900
1000
mb.
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.2 1.4 1.6 1.8 2.0 2.5 3.0 3.5 4.0 4.5 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 23 25 27 30 35
-40 -30 -20 -10 0 10 20 30 40
SPECIFIC HUMIDITY
Gr/Kg
5 4 3 2 1 0
ALTITUDE DYN. KM.
0 50 100
R.H. %

EXAMPLE # 9.

Scott Field, Illinois. 5 May, 1936.

This is type # 3, warm front thunderstorm situation.

The synoptic chart shows a somewhat complicated frontal system about 130 miles southwest of the station. It will act more or less as a warm front and is moving very slowly northeastward. The station lies in RPco under the warm front, with Tg_2 over-running. Inspection of the sounding shows that the frontal zone is at an altitude of approximately 2000 meters.

An inspection of the upper winds shows that the air now at Oklahoma City is the closest approximation the forecaster can obtain to that which will be over-running the station during the forecast period. Examination of the Oklahoma sounding shows that the air up to 2580 meters is in neutral equilibrium for the saturated state but conditionally unstable above that point. However, since the θ_E is only reported to the nearest whole degree, it is advisable to plot the sounding on the adiabatic chart and lift the mass 1300 meters, which is sufficent to saturate the apparently neutral layer. Upon performing this operation it is found that a slight degree of instability does exist above the third point from the surface.

At this stage another factor must be considered; the forecaster is dealing with a warm front, and although convergence may be present in the old polar air beneath the front, the flow in the warm air over the front is anti-cy-

clonic and therefore some divergence is present. This as previously mentioned, will increase the instability of the Tg_2 air after it has become saturated and its conditional instability realized.

This factor should be the decisive one and a mild thunderstorm forecast for the station. The curve has been drawn for the Tg after being lifted 2000 meters, this being approximately the height of the front over the station. However, in arriving at the thunderstorm forecast, it must be borne in mind that instability was developed after a lift of 1300 meters and that the rising particle has been accelerated, before reaching the ICL, for 700 meters more than shown on the adiabatic chart, or a total distance of 1870 meters.

A mild thunderstorm occurred over the station at 1400 E.S.T., accompanied by light rain.

TIME SOUNDING 0400 EST

COMPUTED BY

CALIFORNIA INSTITUTE OF TECHNOLOGY

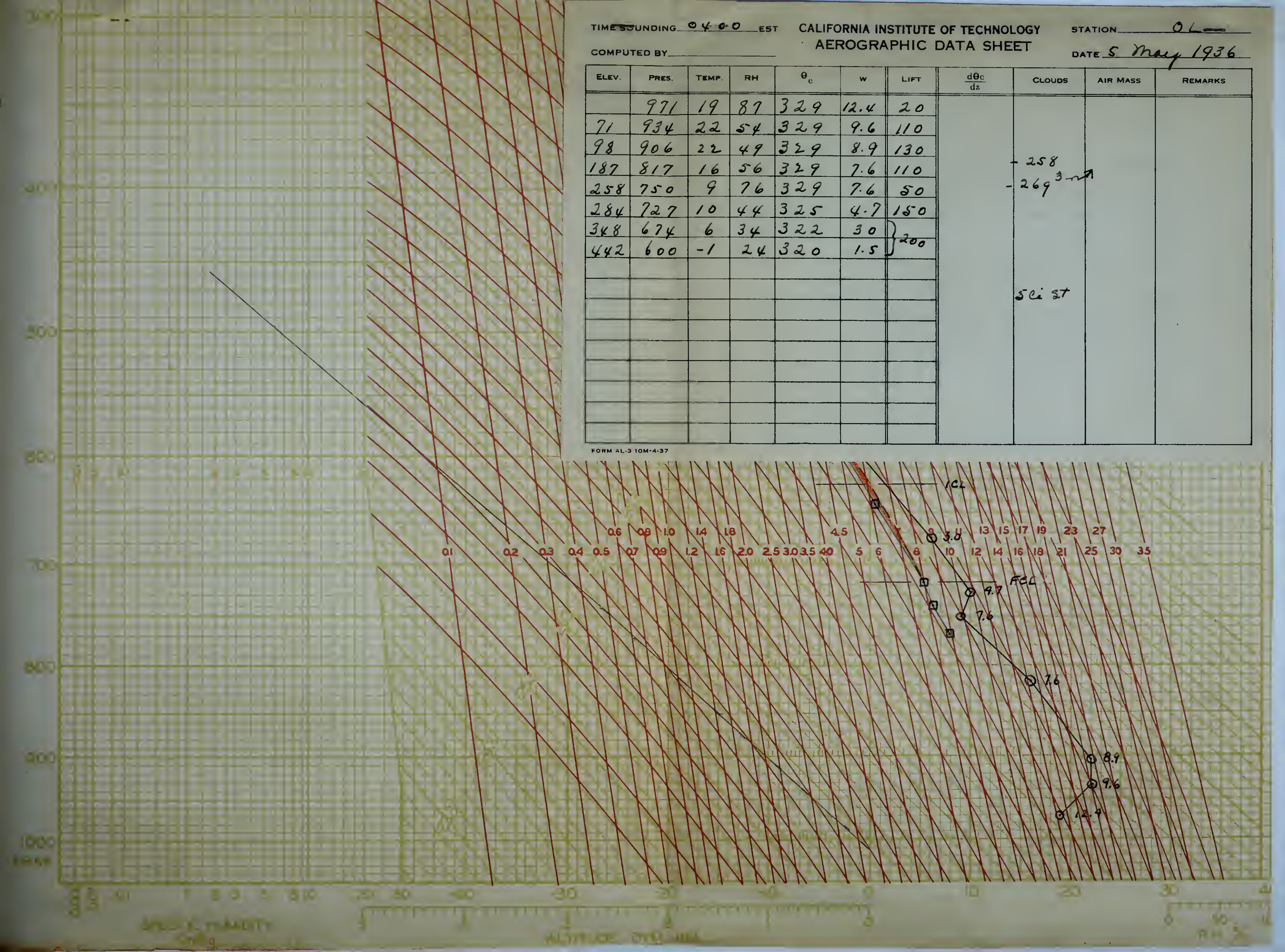
AEROGRAPHIC DATA SHEET

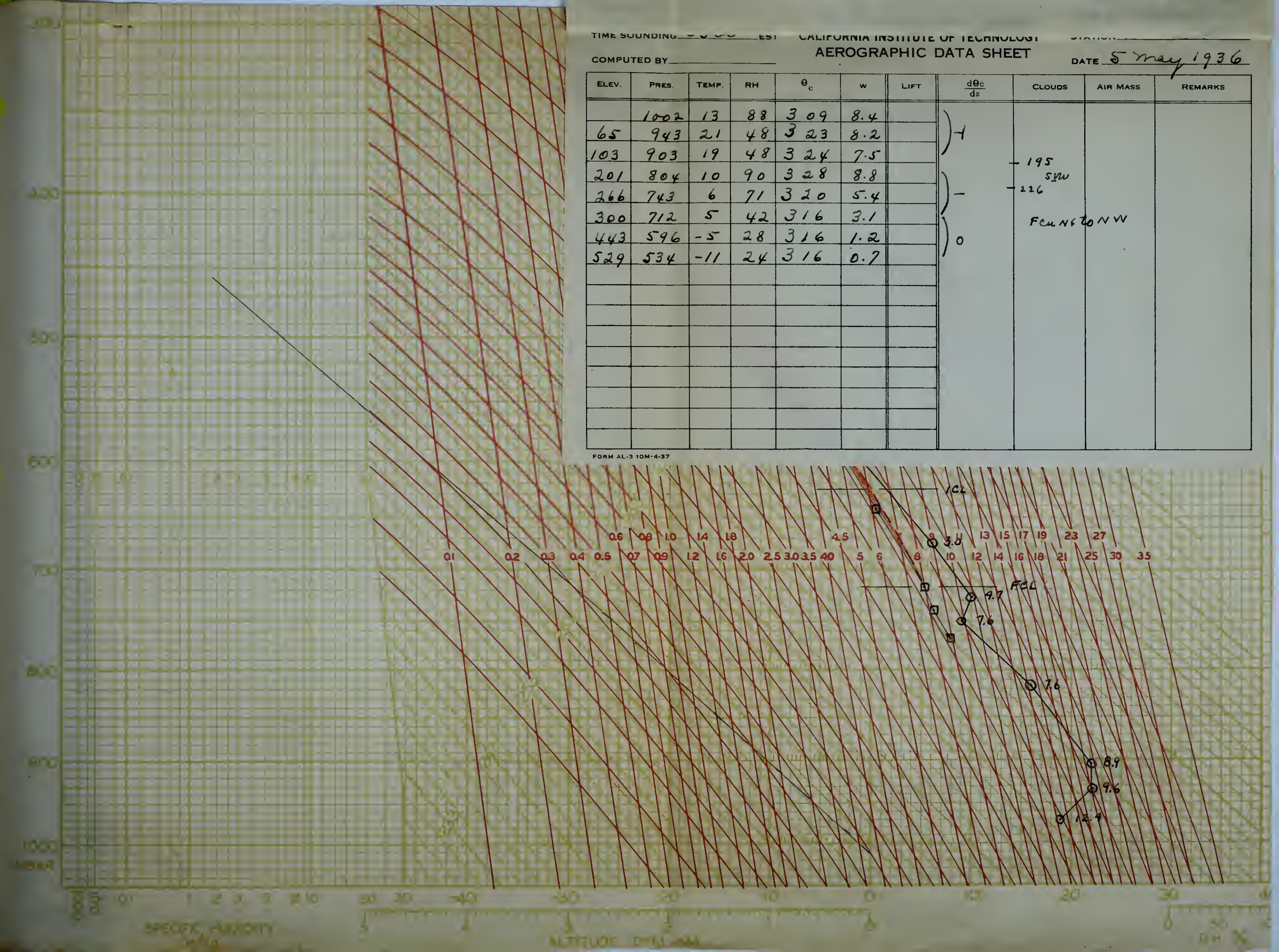
STATION OL

DATE 5 May 1936

ELEV.	PRES.	TEMP.	RH	θ_c	w	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	971	19	87	329	12.4	20				
71	934	22	54	329	9.6	110				
98	906	22	49	329	8.9	130				
187	817	16	56	329	7.6	110		- 258		
258	750	9	76	329	7.6	50		- 269 3 m		
284	727	10	44	325	4.7	150				
348	674	6	34	322	3.0	} 200				
442	600	-1	24	320	1.5					
								5 Ci St		

FORM AL-3 10M-4-37





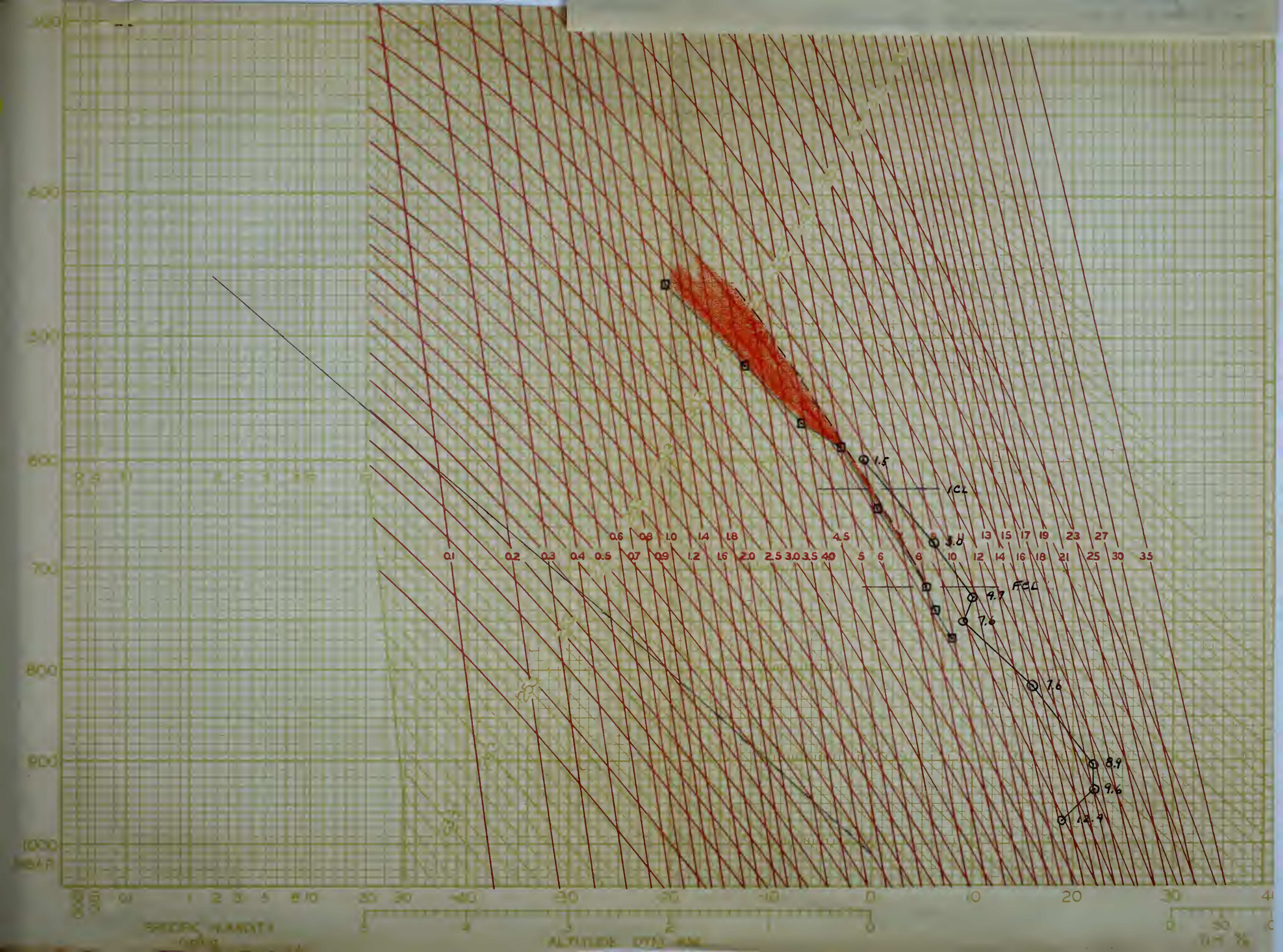
TIME SOUNDING ________ EST CALIFORNIA INSTITUTE OF TECHNOLOGY STATION ________

AEROGRAPHIC DATA SHEET

COMPUTED BY ________ DATE 5 May 1936

ELEV.	PRES.	TEMP.	RH	θ_c	w	LIFT	$\frac{d\theta c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1002	13	88	309	8.4					
65	943	21	48	323	8.2		-1			
103	903	19	48	324	7.5			– 195		
201	804	10	90	328	8.8			SW		
266	743	6	71	320	5.4		–	– 226		
300	712	5	42	316	3.1			Fcu N to NW		
443	596	-5	28	316	1.2		0			
529	534	-11	24	316	0.7					

FORM AL-3 10M-4-37



1.5
ICL
3.0
FCL
9.7
7.6
7.6
8.9
9.6
12.4
0.6 0.8 1.0 1.4 1.8 4.5 13 15 17 19 23 27
0.1 0.2 0.3 0.4 0.5 0.7 0.9 1.2 1.6 2.0 2.5 3.0 3.5 4.0 5 6 8 10 12 14 16 18 21 25 30 35
600
700
800
900
1000
MBAR
-40 -30 -20 -10 0 10 20 30
SPECIFIC HUMIDITY
ALTITUDE DYN. KM

SYNOPTIC SITUATION 31 March-2 April, 1936.

This situation is presented as an example of the manner in which a deep low pressure area in the Rocky Mountain states will induce a flow of Tg air to the east of the Rockies and produce widespread thunderstorms throughout the Mississippi Valley and the Southwest.

The synoptic chart for 0800 E.S.T. on 31 March, shows a deep low, 29.2", centered in northeast Nevada and a front separating Pc and Tg or Np lying inland from the East and Gulf Coasts. This front had moved down rapidly from the northwest during the preceding day but the southern part is now decelerating as shown by the fact that the pressure tendencies on both sides of it are very nearly equal.

Although at the surface San Antonio is in the Pc_4 air, the cloud drift is from the southeast and several stations to the north report alto-cumulus from the southwest. This would suggest over-running of the Pc by Tg air, a fact confirmed by the sounding at San Antonio, which shows a large increase of Θ_E at 980 meters, from 312° at the surface to 332° at this point. The structure from this point upward is conditionally unstable and the values of the lift required show that an additional 1000 meter lift will be sufficent to release the conditional instability of the air. Since the cloud drift has indicated this to be taking place, thunderstorms are to be expected in eastern central Mississippi Valley during the next twenty four hours.

The map for 1 April shows that the expected development has taken place, although the thunderstorms did not develop until 2100 on 31 March, and none are reported in western Oklahoma. This is probably due to the fact that the air over-running the front in western Texas is oPp_2 which is not unstable. The wave located in eastern Texas on the 31 March map is now centered in northern Mississippi, with large negative tendencies to the northeast of it, indicating a deepening with a consequent southeasterly movement of the cold front behind it. The aerograph sounding for Shreveport for this morning definitely shows that Tg air with considerable conditional instability is moving northward over the warm front.

The map for 2 April shows this development to have taken place; the southern section of the front is now in the Gulf, and an easterly movement indicated for the entire front. During the period from 0800 1 April to 0800 2 April the thunderstorm area moved to the eastward but did not decrease in size; in fact the intensities increased due to the front and instability.

The anticipated movement from 2-3 April can be expected to remove the Tg air from the continent and the map of 3 April shows the entire United States, west of the Rockies, invaded by Pc air.

~~TIME~~ SOUNDING 0400 EST

CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

STATION Z N —

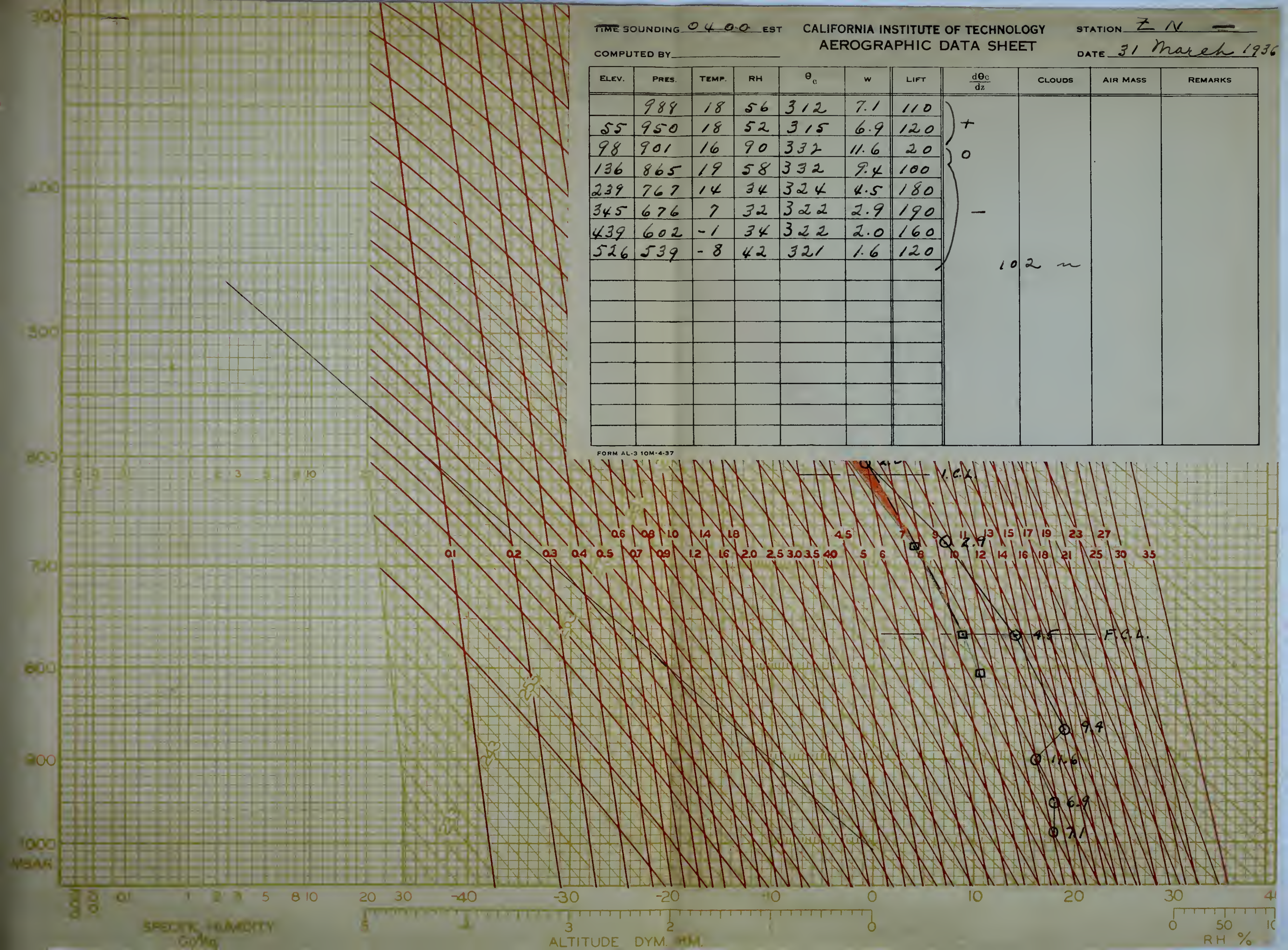
COMPUTED BY ____________

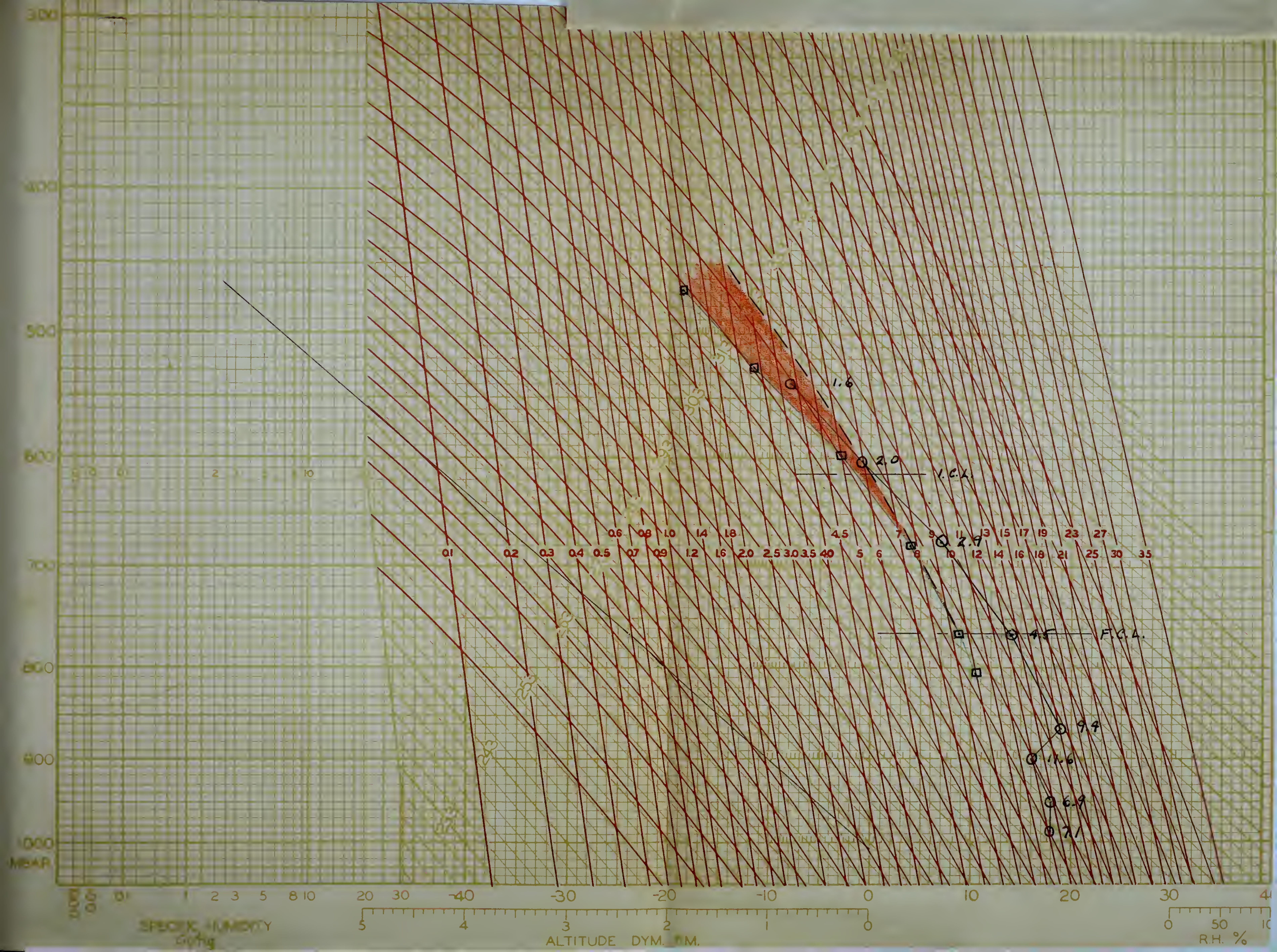
DATE 31 March 1936

ELEV.	PRES.	TEMP.	RH	θ_c	w	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	988	18	56	312	7.1	110				
55	950	18	52	315	6.9	120	+			
98	901	16	90	332	11.6	20	0			
136	865	19	58	332	9.4	100				
239	767	14	34	324	4.5	180				
345	676	7	32	322	2.9	190	−			
439	602	-1	34	322	2.0	160				
526	539	-8	42	321	1.6	120				

102 n

FORM AL-3 10M-4-37





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-10
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40
SPECIFIC HUMIDITY
G/KG
ALTITUDE DYM. KM.
R.H. %
50

TIME SOUNDING 0900 EST

COMPUTED BY

CALIFORNIA INSTITUTE OF TECHNOLOGY

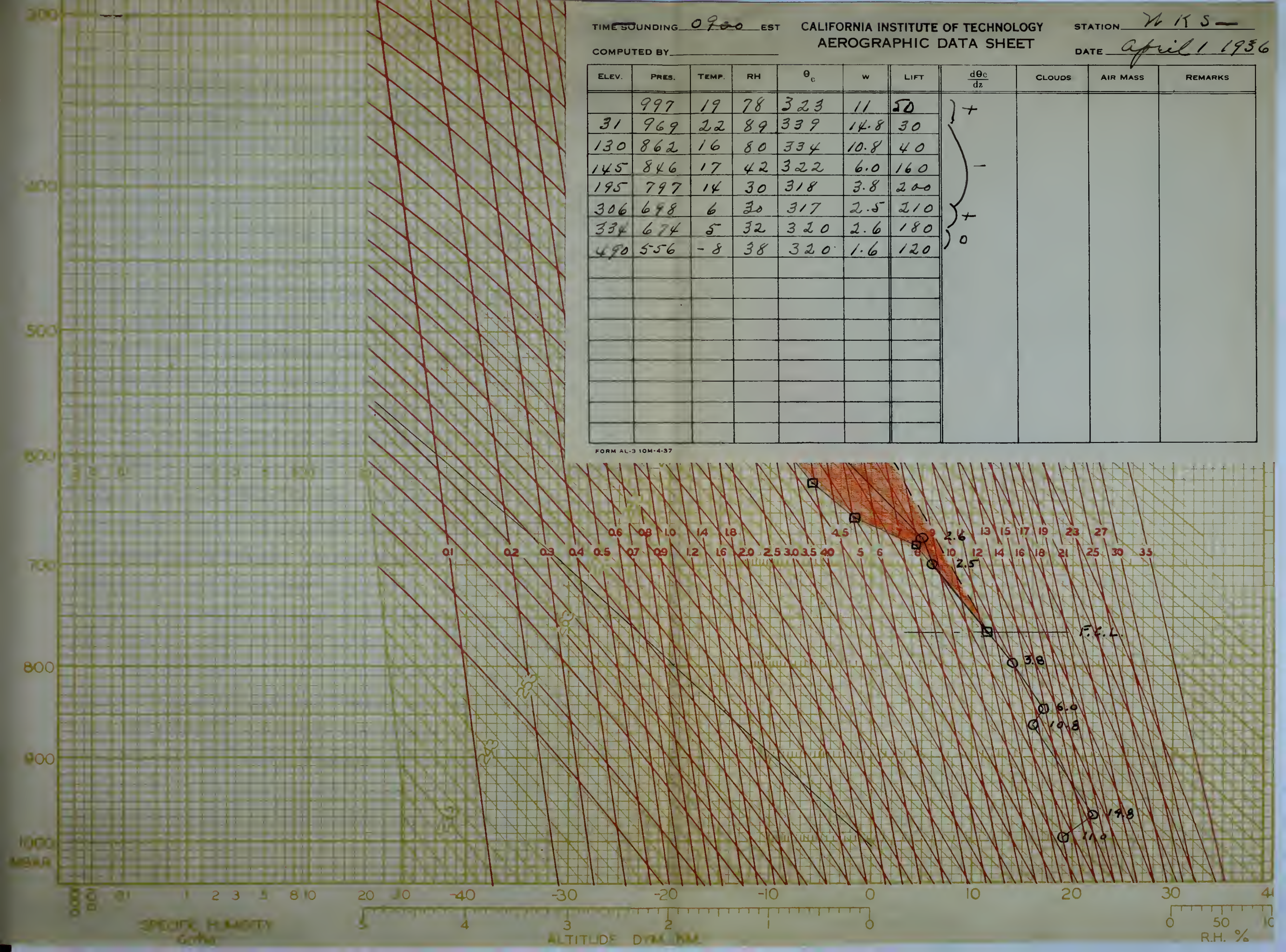
AEROGRAPHIC DATA SHEET

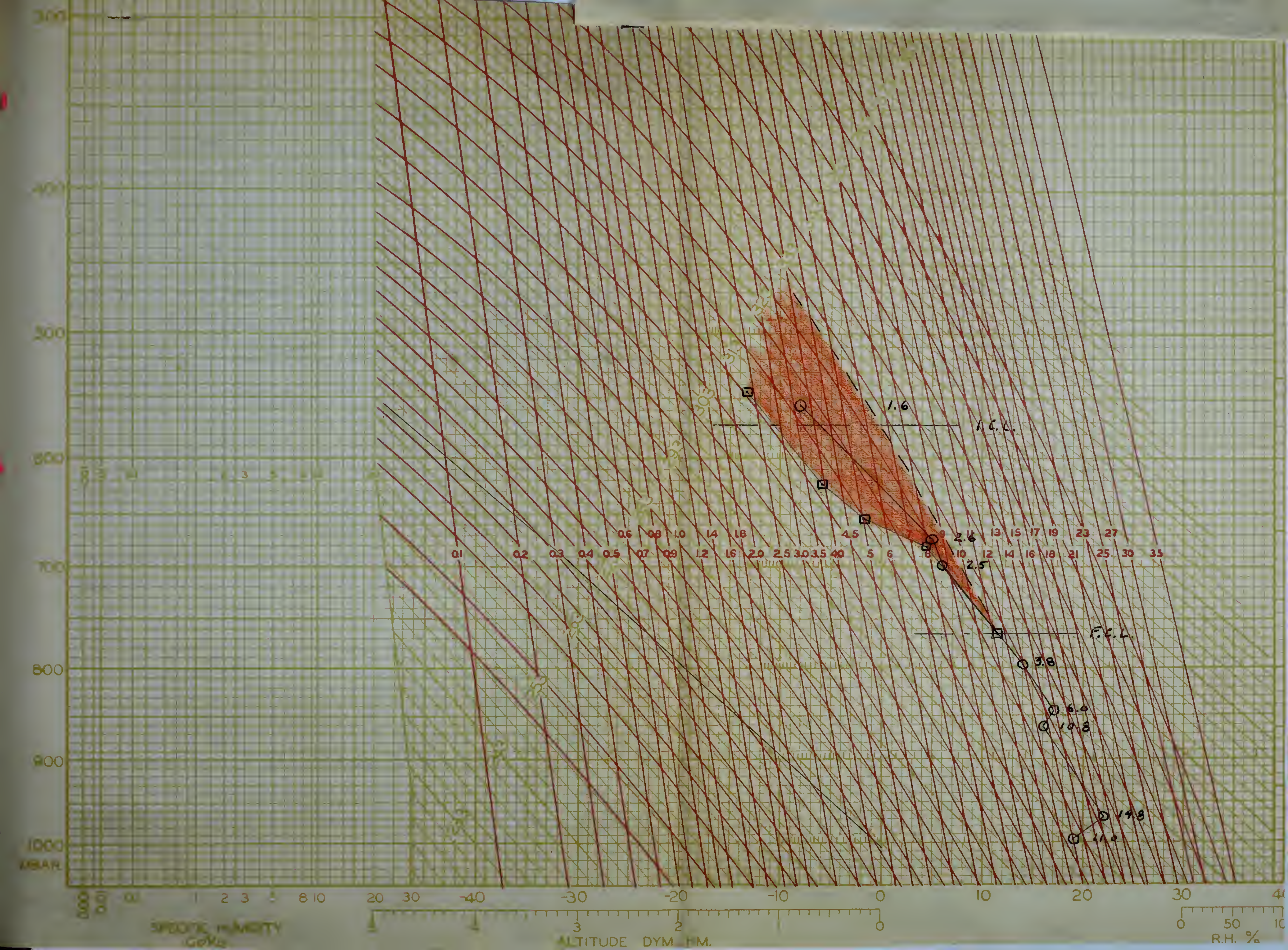
STATION N K S

DATE April 1 1936

ELEV.	PRES.	TEMP.	RH	θ_c	w	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	997	19	78	323	11	50	+			
31	969	22	89	339	14.8	30				
130	862	16	80	334	10.8	40				
145	846	17	42	322	6.0	160	−			
195	797	14	30	318	3.8	200				
306	698	6	30	317	2.5	210	+			
334	674	5	32	320	2.6	180				
490	556	-8	38	320	1.6	120	0			

FORM AL-3 10M-4-37





MBAR.
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I.C.L.
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F.C.L.
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SPECIFIC HUMIDITY
GM/KG
ALTITUDE DYM. KM.
R.H. %

SYNOPTIC SITUATION 25 April-28 April, 1936.

This situation is presented to illustrate the manner in which a warm front with considerable thunderstorm activity is frequently found on a quasi-stationary front lying just east of the Rocky Mountains.

The 0800 map for 25 April shows an almost stationary front separating Pc_5 to the north and a mixture of oPp_0 to the south, running through Colorado, Kansas and Missouri, and a warm front separating the Pp air from RPc_3 located approximately along the Mississippi River. The gradient in Texas and Oklahoma shows that air is being drawn up from the Gulf, a fact which is confirmed by 25 to 30 knot winds in the upper air. Unfortunately there is no sounding from San Antonio on this date to verify the influx of T_g. The upper winds in the highest levels are from the north and northwest, indicating that the air aloft is oPp_0, which has approximately the same temperature as the T_g but contains very little moisture. The presence of a dry layer over a moist one, without the presence of an inversion, produces a high degree of instability, conditional, due to the rapid decrease of θ_E with altitude.

Thunderstorms have already developed along the front in Kansas, Oklahoma and northern Texas by late afternoon on the 25th. The situation has become more obvious on the 0800 map for the 26th. The sounding from San Antonio shows the presence of air approaching the characteristics of T_g, which will be rendered unstable by a 2000 meter lift. No movement is in-

dicated for the front except in west Texas where large positive tendencies indicate a northerly movement.

Thunderstorms have developed all along the front by 2000 26 April, and the 0800 map for 27 April shows a well developed warm front through Kentucky, Missouri and southern Illinois. The sounding from Shreveport shows that the air flowing north over this section is conditionally unstable from 1800 meters to the top of the sounding and requires only a 2000 meter lift to produce instability. The warm front thunderstorms continue throughout the day and scattered air mass thunderstorms are reported along the Gulf Coast.

By the morning of the 28th the T_g is at the surface as far north as the Great Lakes. The soundings from Shreveport and Pensacola (air mass example # 1) show that surface temperatures of 27°8 C. will be sufficent to produce convective thunderstorms, these occurred in the afternoon as far north as Detroit.

TIME SOUNDING 1000 EST

COMPUTED BY

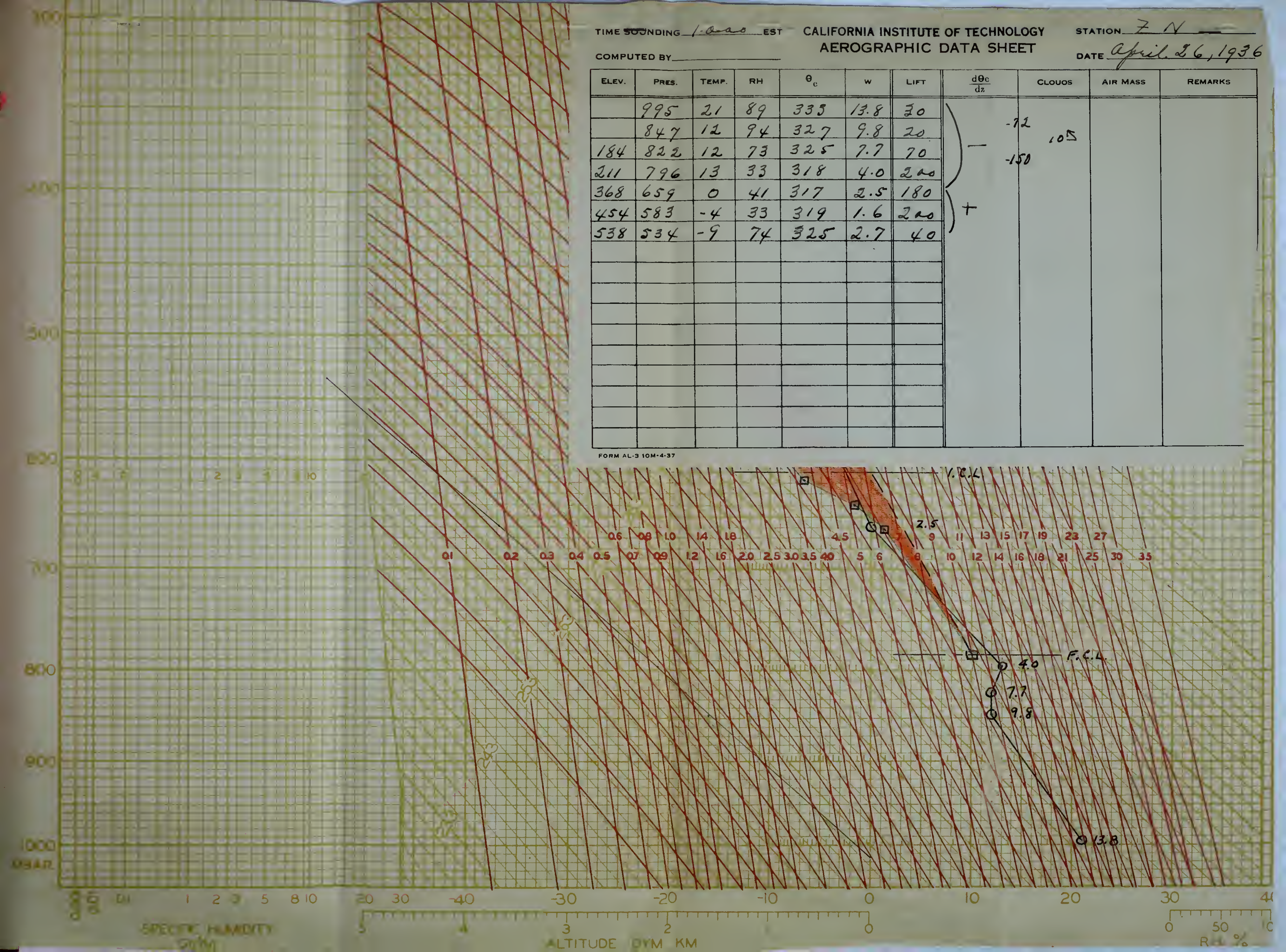
CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

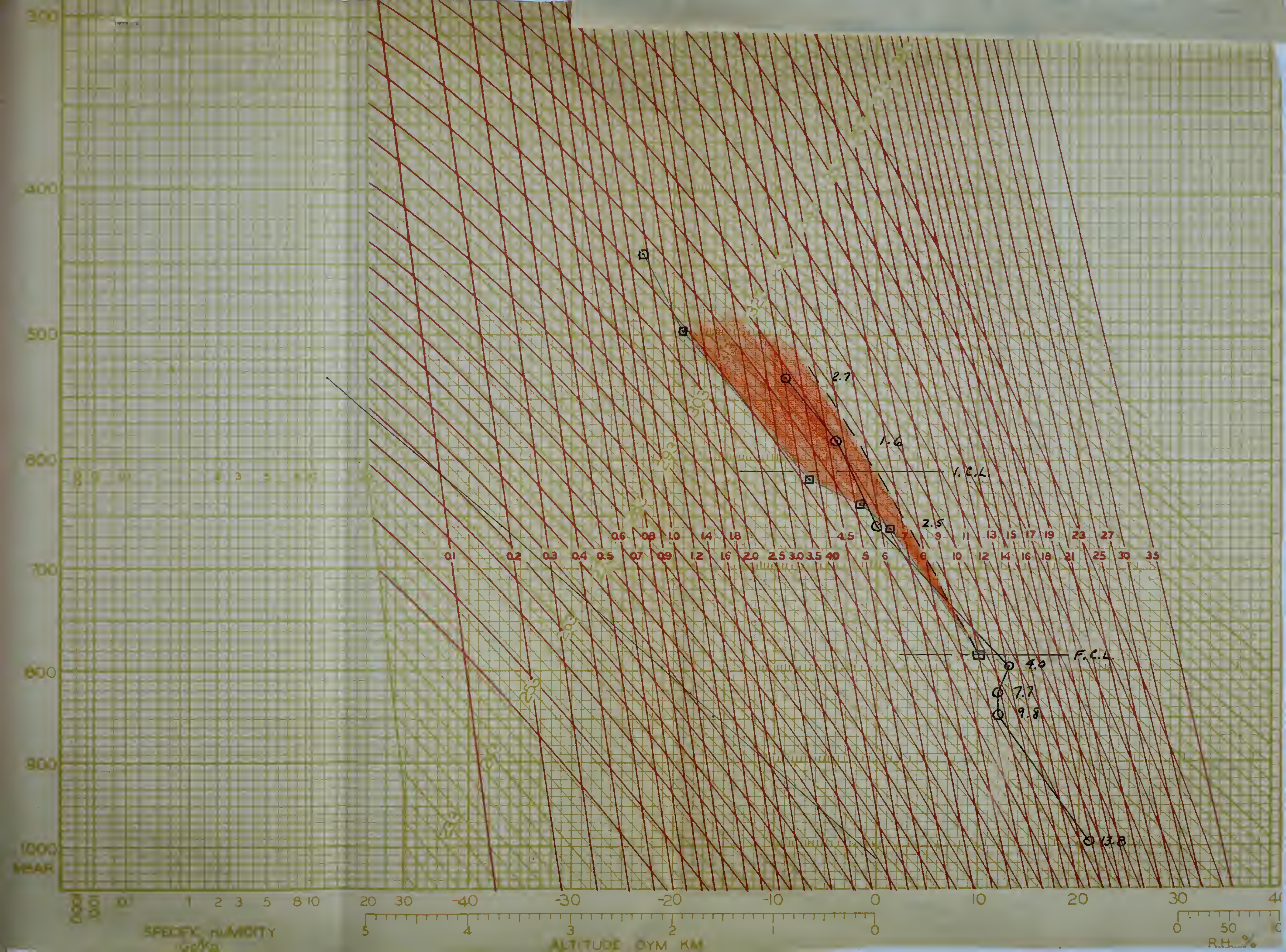
STATION Z N

DATE April 26, 1936

ELEV.	PRES.	TEMP.	RH	θ_c	w	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	995	21	89	333	13.8	30	-72	105		
	847	12	94	327	9.8	20	—			
184	822	12	73	325	7.7	70	-150			
211	796	13	33	318	4.0	200				
368	659	0	41	317	2.5	180	+			
454	583	-4	33	319	1.6	200				
538	534	-9	74	325	2.7	40				

FORM AL-3 10M-4-37





2.7
1.6
I.C.L.
2.5
F.C.L.
4.0
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13.8
SPECIFIC HUMIDITY
ALTITUDE DYM KM
R.H. %
MBAR

TIME SOUNDING 0400 EST

CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

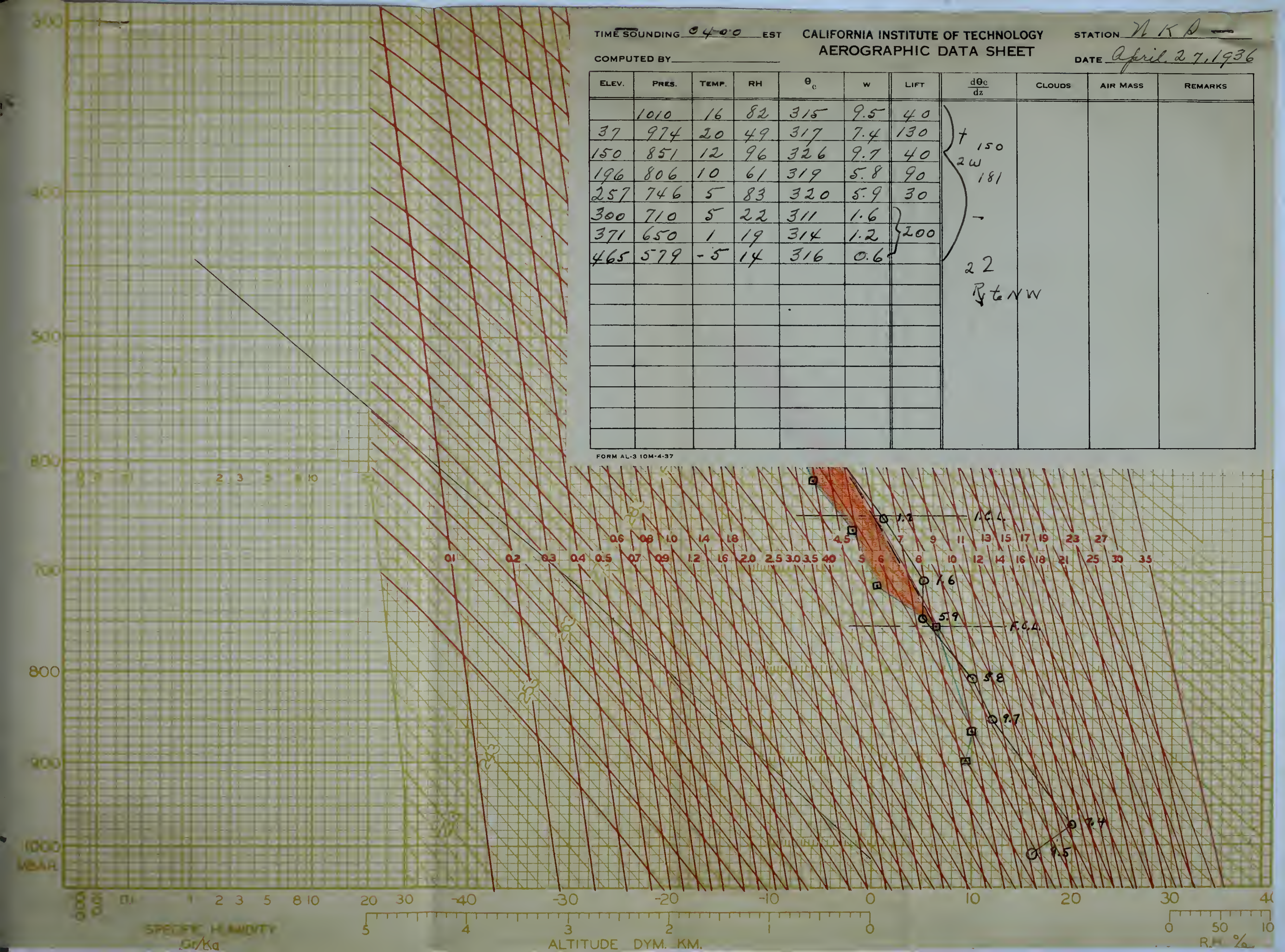
STATION NKD

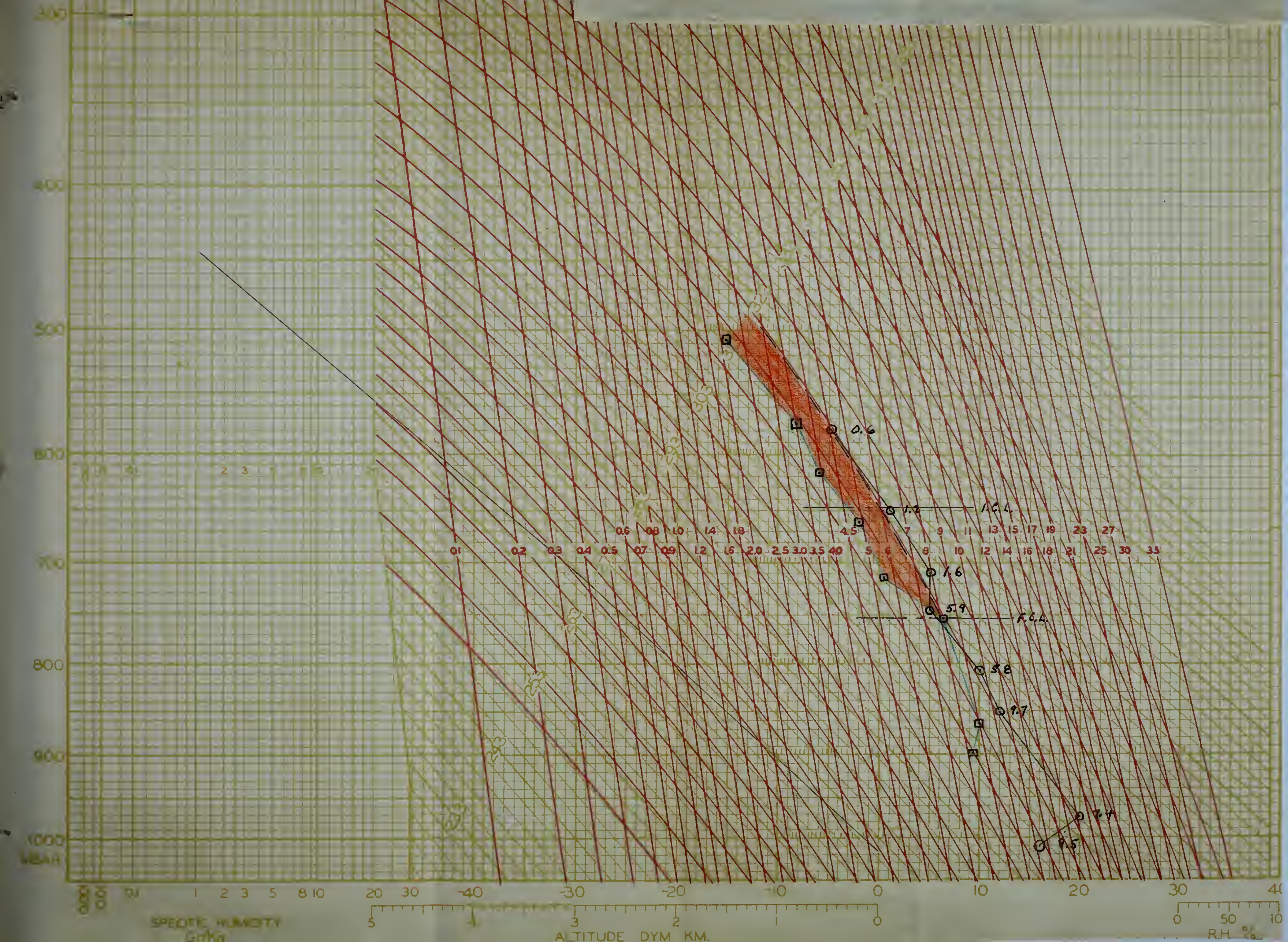
COMPUTED BY

DATE April 27, 1936

ELEV.	PRES.	TEMP.	RH	θ_c	w	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1010	16	82	315	9.5	40				
37	974	20	49	317	7.4	130	+ 150			
150	851	12	96	326	9.7	40	2w			
196	806	10	61	319	5.8	90	181			
257	746	5	83	320	5.9	30				
300	710	5	22	311	1.6	} 200	→			
371	650	1	19	314	1.2					
465	579	-5	14	316	0.6		22			
							R to NW			

FORM AL-3 10M-4-37





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7.4
9.5
-40
-30
-20
-10
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40
SPECIFIC HUMIDITY
G/KG
ALTITUDE DYM KM.
R.H. %

TIME SOUNDING 0400 EST

COMPUTED BY

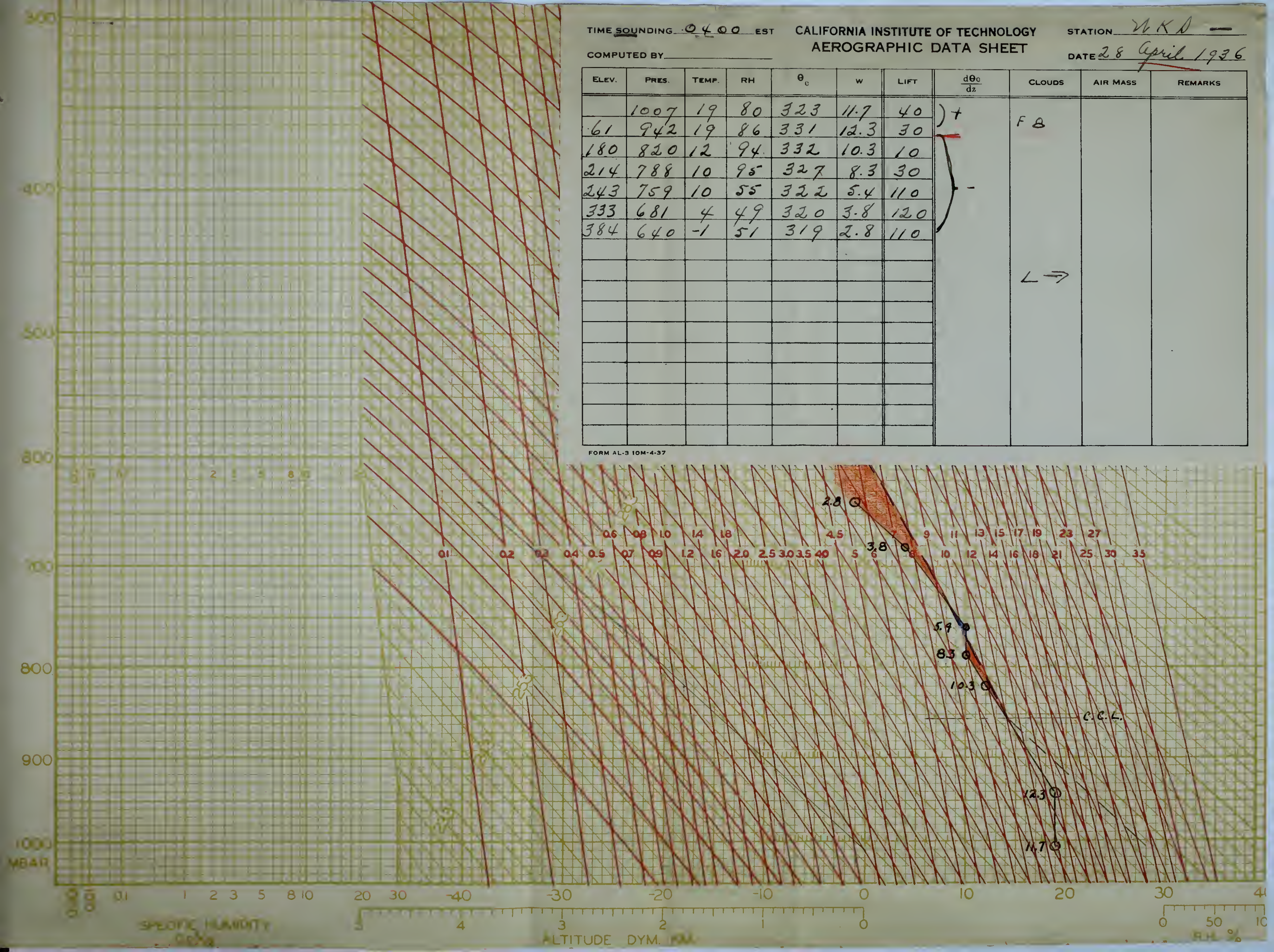
CALIFORNIA INSTITUTE OF TECHNOLOGY
AEROGRAPHIC DATA SHEET

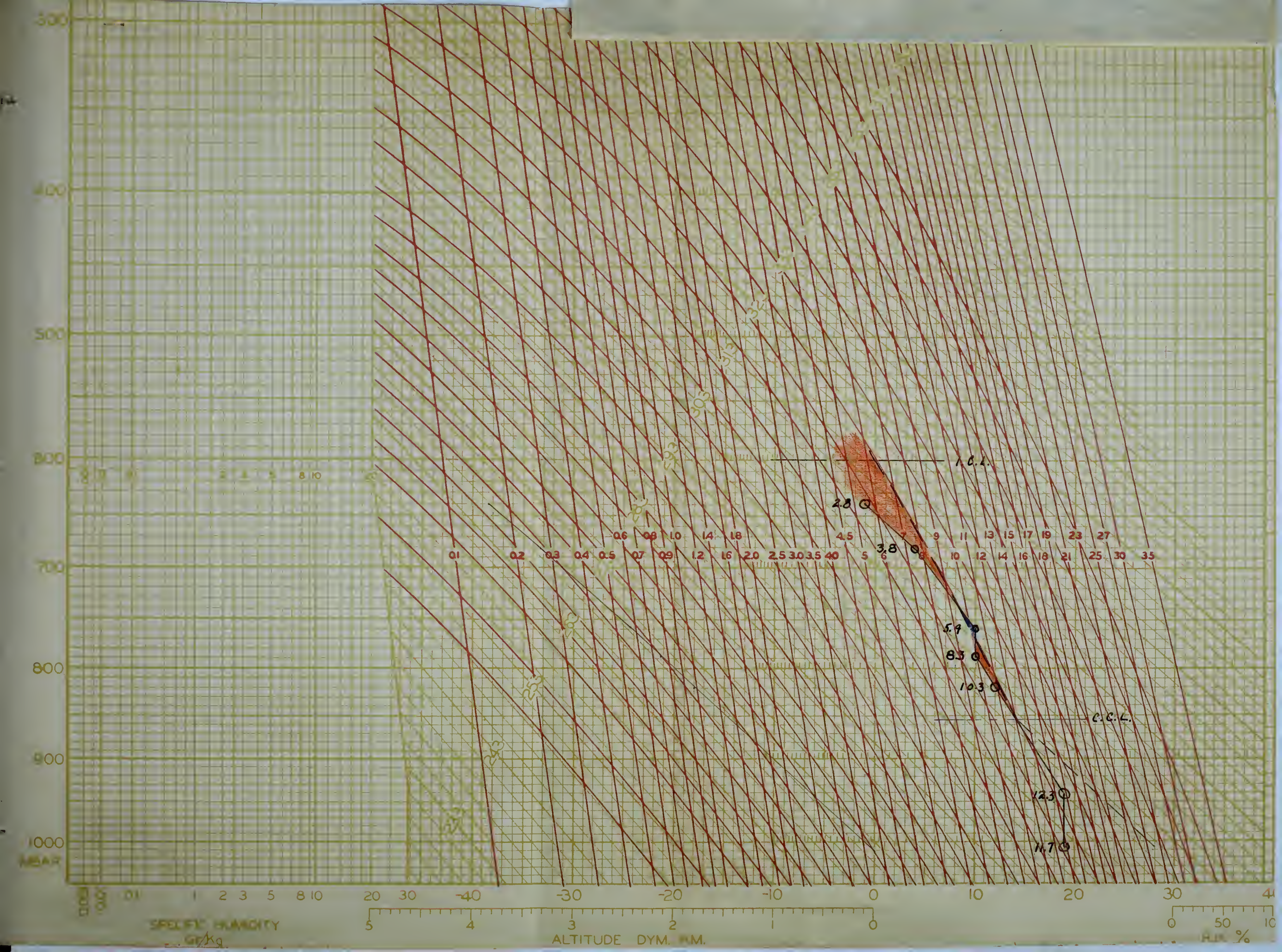
STATION NKD —

DATE 28 April 1936

ELEV.	PRES.	TEMP.	RH	θ_c	W	LIFT	$\frac{d\theta_c}{dz}$	CLOUDS	AIR MASS	REMARKS
	1007	19	80	323	11.7	40	+			
61	942	19	86	331	12.3	30		F 8		
180	820	12	94	332	10.3	10				
214	788	10	95	327	8.3	30				
243	759	10	55	322	5.4	110	-			
333	681	4	49	320	3.8	120				
384	640	-1	51	319	2.8	110				
								L ⇒		

FORM AL-3 10M-4-37





I.C.L.
C.C.L.
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10.3
12.3
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MBAR
SPECIFIC HUMIDITY
GR/Kg
ALTITUDE DYM. KM.
R.H. %

SECTION THREE

Pre-frontal thunderstorms produced by a convergent field of motion.

This type of thunderstorm is given a section in the original classification solely because it has frequently been referred to by others. It is our belief that this designation could as well be; produced by a lift, produced by an orographic obstruction, produced by insolational heating or produced by a combination of these and convergence.

Convergence resists any quantitative analysis. It is known to exist and can be shown, on meteorological charts, to have a decided effect. However, to designate a type of thunderstorm as initiated by convergence seems to suggest that a measure of such convergence can be used to say , "This much convergence will produce so much effect." To date there is no means available with which to measure convergence quantitatively, in practical forecasting.

There is no definite point where it can be said that a prefrontal thunderstorm ceases to be produced by lifting and is produced by a convergent field of motion. In the rare cases of thunderstorms in the cold air under a warm front the cause may just as well be laid to insolational heating as to the effect of the convergent field of motion.

There are undoubtedly thunderstorms produced which can

not be explained on the basis of any one measurable factor, several factors may have contributed to the final impulse which released the potential instability. If, as suggested by the title of this thunderstorm type, there is frontal activity present then there is certainly lifting of the air into which one air mass is intruding, in the case of the cold front, and there is also vertical motion in the cold air underlying, in the case of the warm front. Where this lifting, or vertical motion, initiates is no more and no less intangible than the amount of convergence present; but it too has its effect in the production of a thunderstorm.

If one is in doubt as to the exact cause of a thunderstorm it would appear that calling it a separate type, produced by an unmeasurable, intangible cause is not wholly justified.

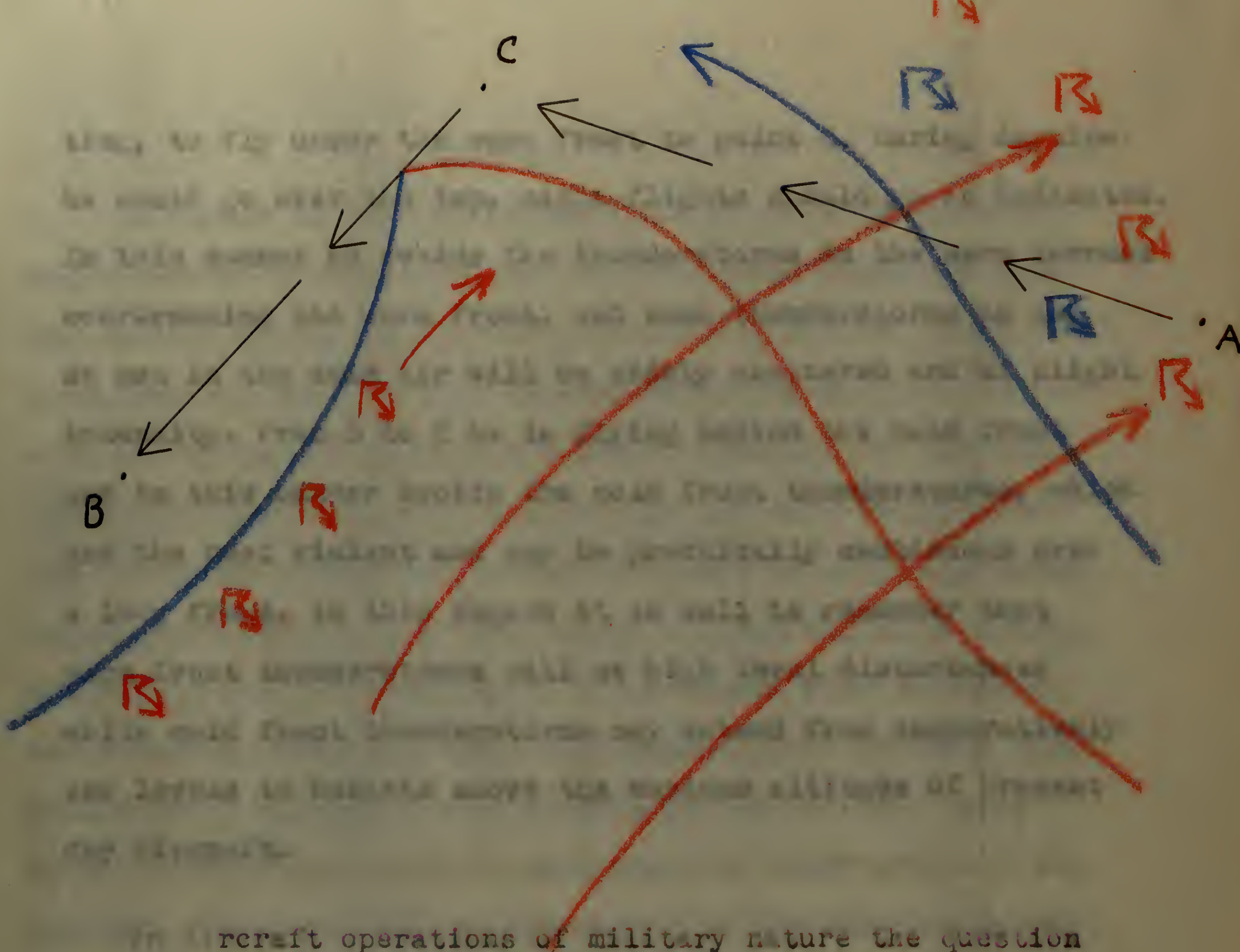
The types listed in sections one and two, together with variations in expected position of development which may be attributed to trajectories from the point of inception of convective activity to the point of realization of the thunderstorm, seem sufficent to explain the thunderstorm phenomena with which the forecaster can successfully deal.

Trajectories of thunderstorms.

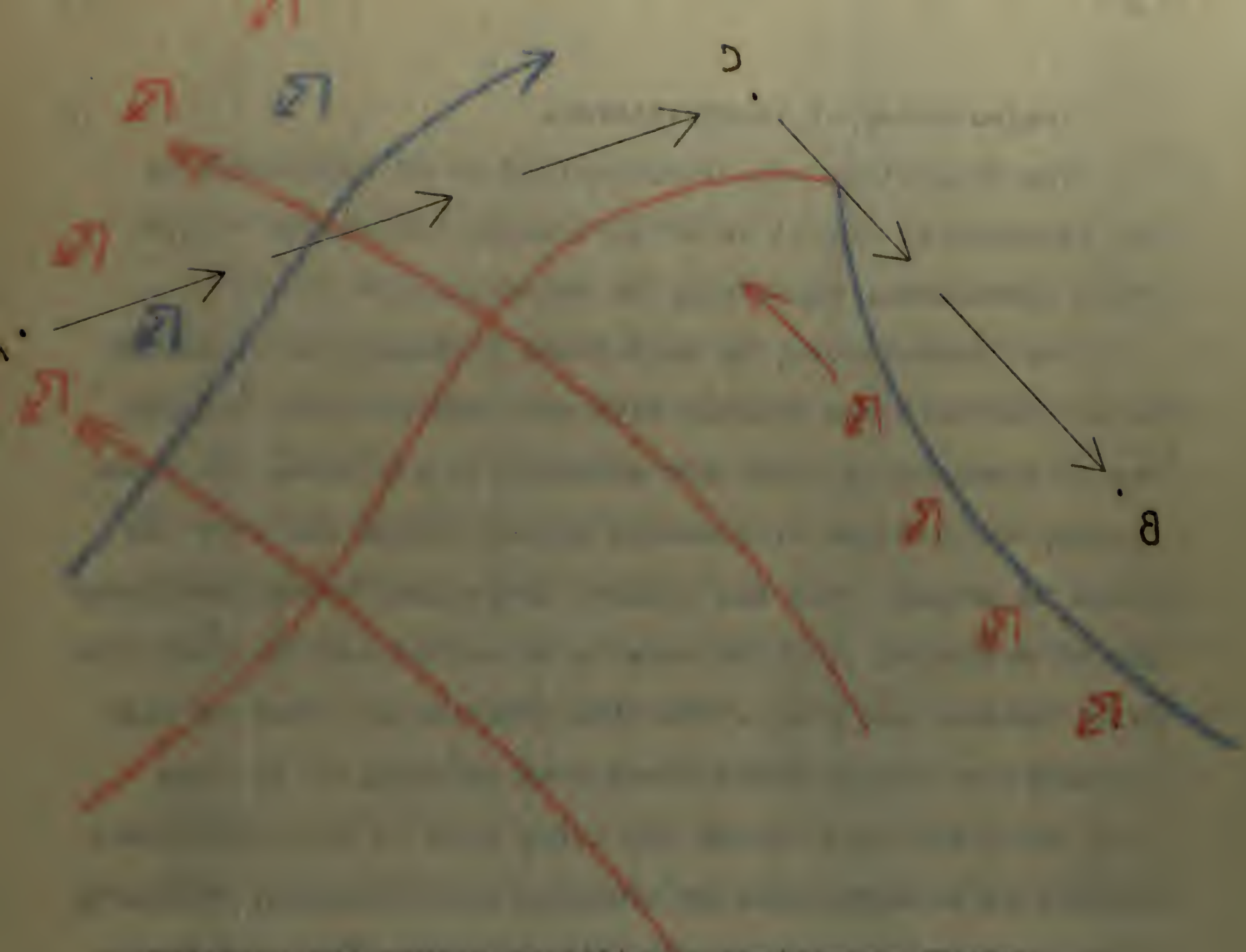
The trajectory of a thunderstorm is of importance to any forecaster, but it is of particular importance in aircraft operations, especially on scheduled air lines.

Any thunderstorm, no matter how produced, is contained in one air mass and travels with the general flow. In this manner convections which are produced in one area, and maintained, may produce or continue thunderstorms far from the point of origin. Thus the general trajectory of thunderstorms may be estimated from the upper wind velocities obtained from pilot balloon soundings. From the forecasting point of view knowledge of thunderstorm conditions existing in an area from which the upper winds may carry them to the forecasters station is of importance in arriving at a forecast. Similarly local topography may favor the development of thunderstorms, in certain situations, which will be carried to the station in the general drift; the almost daily occurrence of summer afternoon thunderstorms near Denver is an excellent example of this condition.

The extra-tropical cyclone with an open warm sector gives an excellent example of possible thunderstorm trajectories. While not a wave formation in the strict sense, a configuration similar to this is a frequent occurrence in the Middle West.



In aircraft operations of military nature the question of flight paths to avoid thunderstorms is to be answered by convenience or necessity; but in the case of scheduled air line operations such flight paths can and should be the consideration of the despatcher. A knowledge of the place of formation, altitude, probable path and velocity of the thunderstorm will enable the flight path to be plotted to avoid the area of greatest intensity. Thus a condition similar to the diagram above, when it is desired to clear an aircraft from point A to B, should lead to a decision to order the flight to follow the flight path A-C-B. In this flight he would fly at a sufficiently low altitude, topography permit-



ting, to fly under the warm front to point C. During daytime he could go over the top, night flights should go as indicated. In this manner he avoids the thunderstorms in the warm current over-running the warm front, and such thunderstorms as may be met in the cold air will be widely scattered and of slight intensity. From B to C he is flying behind the cold front and in this manner avoids the cold front thunderstorms, which are the most violent and may be practically continuous over a long front. In this regard it is well to remember that warm front thunderstorms will be high level disturbances while cold front thunderstorms may extend from comparatively low levels to heights above the maximum altitude of present day aircraft.

GENERAL

In regard to the most probable hours of occurrence of thunderstorms a wide variance is to be found depending upon the various types, and the terrain over which they occur, land areas or sea. Frontal thunderstorms may occur at any time of the day or night since their formation is independent of the temperature of the surface and is a function of the movements of the air masses involved. If anything, frontal thunderstorms should reach their maximum intensity during the night, due to a steepening of the lapse rate by radiational cooling from the top of the cloud layer. However, this effect would scarcely be noticeable in a cold front type, since it would be slight in proportion to their original intensity. The warm front thunderstorm, on the other hand, may be intensified, or even initiated by radiational cooling. Orographical thunderstorms may also occur at any hour, but they are more frequent during the late afternoon and evening when convections due to surface heating assist in their development; at night a fairly strong flow is required to overcome the mountain breeze effect and still produce thunderstorms.

Convective thunderstorm activity, due to insolational heating, is limited to the late afternoon and evening, over land areas, since the forces which produce them are a maximum at that time. In fact these forces disappear at night, although the thunderstorms may be maintained for some hours

after sunset by radiational cooling from the top of the cloud. Observations show that air mass thunderstorm activity over the oceans has a maximum during the early morning hours and is a minimum during the daylight hours. The commonly accepted theory explaining this period of thunderstorm activity, ascribes the development of necessary instability to radiational cooling of the upper air, while the surface layers retain their practically constant temperature due to the presence of the water surface. Advection at certain levels may also produce a steepening of the lapse rate and promote thunderstorm activity. No data illustrating this are available since, at present, no soundings from ships at sea are obtainable.

The development and use of the radio meteorograph will undoubtedly lead to a much more complete knowledge and understanding of thunderstorms, since in the great majority of cases the activity extends far above the heights now reached by aerograph soundings. No accurate forecast as to the type of precipitation or intensity of the thunderstorm can be made so long as the shape of the curves above the limit of the aerograph sounding is a matter of conjecture.

SUMMARY

Since many of the ideas involved in forecasting thunderstorm development are widely scattered throughout this paper, it has been deemed advisable to collect some of the more important in an outline of suggested procedure.

1. Referring to the synoptic chart, determine what air masses will be over the station during the forecast period.

2. Considering the trajectory of the air, plot the sounding which most nearly approximates the air mass expected and determine the temperature required to produce free convections, and the lift necessary if orographical lifting is possible. Estimate the probability of the required temperature being attained from the diurnal temperature curves.

3. If any frontal passages are expected during the forecast period, determine the amount of lift required to produce instability.

4. From a knowledge of the synoptic situation, estimate the changes which will take place in the structure of the air during the forecast period and their effect upon its stability.

5. Having arrived at a decision regarding the type of thunderstorm to be expected, from the size of the positive area, and its location on the adiabatic chart, estimate the intensity of the thunderstorm and type of precipitation to be expected.

6. From a knowledge of local conditions, make an estimate regarding the possibility of thunderstorms, which are developed elsewhere in especially favorable locations, being carried to the station in the general drift.